THE INSTRUMENT ASPOC AND THE CLUSTER ACTIVE ARCHIVE

H. Jeszenszky, K. Torkar, G. Laky

Space Research Institute, Austrian Academy of Sciences, Schmiedlstraße 6, 8042 Graz, Austria,
Email:harald.jeszenszky@oeaw.ac.at

ABSTRACT

The instrument ASPOC (Active Spacecraft Potential Control) controls the electric potential of the Cluster spacecraft by emitting an energetic ion beam. Thereby the conditions for the plasma measurements on board improve, and beneficial effects have been observed for the electric field measurements. As the instruments are only active in part of the mission, comprehensive knowledge about the status of the instruments including the ion beam current at the highest available temporal resolution, the energy of the ions and other parameters are highly useful for the interpretation of plasma, electric field, and spacecraft potential data from Cluster. The data sets and auxiliary information for ASPOC in the Cluster Active Archive, and the current status of the archiving activities for ASPOC are described.

1. INTRODUCTION

The instrument ASPOC (Active Spacecraft Potential Control) has been described in [1]. It controls the electric potential of the Cluster spacecraft by emitting a beam of Indium ions (115 amu) at energies of 5 to 9 keV. In steady state, without artificial ion emission, a spacecraft will charge to an equilibrium potential where all currents, mainly the current of photo-electrons generated at the spacecraft surface and currents due to the ambient plasma are balanced. In tenuous plasma such as in the lobes of the magnetosphere this equilibrium is not only strongly fluctuating together with the variations of plasma density, but also the absolute value of the potential easily reaches tens of volts positive. The effect on the photo-electrons is that almost all electrons generated at the surface will return and thereby also enter into the plasma electron detectors, where the resulting high count rates lead to faster aging of the micro-channel plates. Particle energies and trajectories - both electrons and ions - are modified by the electric field around a charged spacecraft body, complicating the interpretation of the distribution functions and making the accurate calculation of bulk parameters very difficult, if not impossible. The improvement of the electron measurements by controlling the spacecraft potential is illustrated by Fig. 1 adapted from [2]. Only after the turn-on of the ASPOC ion beam at 0733 UT, which reduces the spacecraft potential from 35 V to 7 V, the features at low energies become clearly visible.

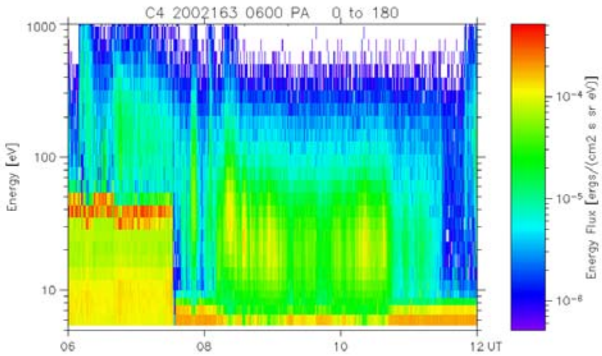

Fig. 1. Electrons from the PEACE LEEA sensor of Cluster 4 averaged over all pitch angles on June 12, 2002, from 06 to 12 UT (after [2]).

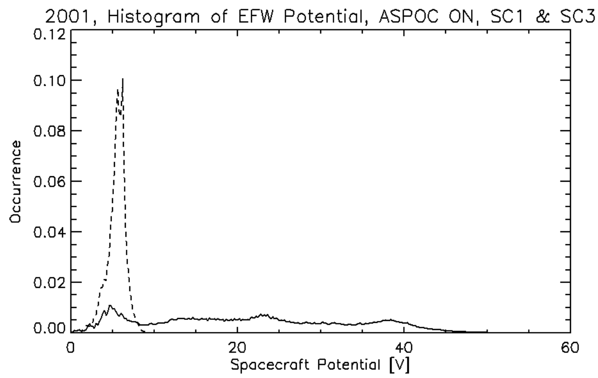

Fig. 2. Histograms of spacecraft potential on Cluster 1 (full line) and 3 (dashed line) during intervals with active ion beam on Cluster 3 (adapted from [3]).

The sheath around a highly charged spacecraft may grow to large extensions of several tens of meters. Measurements of the electric field by double probes may suffer from a large sheath. In certain environments of a low density, but cold plasma, this may lead to significant deviations. It is clear that the control of the spacecraft potential improves the conditions of the measurements by plasma detectors and also may help the double probe measurements, but being an active experiment, the instrument ASPOC introduces changes to the conditions of these measurements. Fig. 2 adapted from [3] shows histograms of spacecraft potential measured during simultaneous periods in 2001 with and

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without ion beam (Cluster 3 and 1, respectively). Obviously, the presence and value of the ion beam current must also be taken into account when using the spacecraft potential as a proxy for ambient plasma density.

In brief, complete knowledge about the status of the spacecraft potential control, the characteristics of the ion beam is essential for the correct interpretation of Cluster electron (instrument PEACE), ion (CIS), and double probe electric field as well as spacecraft potential data (EFW). Obviously, the latter are most directly influenced by the operation of the ASPOC ion beam. This intimate relationship between ASPOC beam current, spacecraft potential, and onboard plasma measurements needs careful consideration in all accurate studies involving these parameters.

2. INSTRUMENT CHARACTERISTICS

2.1 Ion Emitters

In order to interpret the datasets properly it is necessary to understand the basic features of the instrument hardware. At the heart of ASPOC are emitters of the liquid metal ion emitter type with indium as charge material. Before any ion emission can take place, the indium has to be molten by means of a small electrical heater which is in thermal contact with the reservoir. The melting of the indium from the cold state lasts about 15 minutes in a mode called “start-up”, after which high voltage is applied and successively increased until the field emission process ignites. The emission current is then electronically controlled, while the extraction voltage adjusts itself within the range of the electrical supply. The emitters are arranged in two “modules” with four emitters each, and the emitters are operated one at a time.

2.2 Currents in the Emitter System

For a better understanding of the behaviour of the ion beam current it is necessary to briefly describe the relevant currents flowing in the emitter system:

1. The current carried by the emitted ion beam. This current loop is closed via the spacecraft surface by the ambient plasma. This current is referred to as ion current or beam current.

2. The total current delivered by the high voltage supply to the emitter. This current includes the beam current and internal loss currents (e.g. the current to the extraction and beam focusing electrodes), and may therefore be larger than the beam current. The percentage of loss currents within the total current is small (0 to 20%) for small to medium currents and may increase to 30 to 50% near the maximum total current of about 50 μA.

The typical emission currents applied in Cluster lie in the 10 to 16 μA range. They put an upper limit to the spacecraft potential on the order of 6 to 8 V. The emission current of an emitter may be increased to maximum current over a short period (between 30 seconds and a few minutes) as a precaution to remove any contamination from the emitter, thereby ensuring that the operating voltage remains within operational limits. This procedure is called "cleaning".

2.3 Instrument Modes

The default active mode of the instrument fixes the total current of the high voltage unit, including losses inside the lens system (mode ITOT). Experience has shown that the resulting emission of an almost constant ion current fulfils all requirements for spacecraft potential control in the magnetosphere and the solar wind even without on-board feedback from measurements of the spacecraft potential.

The second stand-alone mode active mode controls the ion emission current to a constant value (mode IION). In this mode, the output current remains constant despite of any variable internal loss currents.

In the two available, so-called feedback modes, a measurement of the spacecraft potential is supplied to ASPOC by either the electric field experiment (EFW) or the electron analyser (PEACE) and this information is then used to adjust the emission current sufficient to reduce the potential to some predetermined value in a closed-loop scheme. This mode is called feedback mode with EFW (mode "FEFW") or feedback mode with PEACE (mode "FPEA"). The measurements of the spacecraft potential are updated once every spin and sent to ASPOC via dedicated serial, digital inter-experiment links. Data from EFW consist of the voltage measured between one pair of spheres and the spacecraft body when operating in voltage mode. The value is sampled every second and sent to the Digital Wave Processor (DWP) instrument, which combines it with operating mode information of the WHISPER instrument and transmits the product to ASPOC. If no data are available in feedback mode, ASPOC will return to a previously commanded "backup" mode, which can be another active mode or standby mode.

In standby mode (STDB) both the emitters and their heaters are turned off. The standby mode is also the safe mode of the instrument, to which it returns autonomously under certain error conditions. The command into standby mode also clears all error flags, clears the previous emitter and module selection, disables high voltage, and disables the heaters.

In order to reduce the time before emission starts, a “hot standby” mode (HOTS) keeps the indium in a liquid state. This mode can be used to interrupt the ion emission by command, without change of modes or emitters before and after the break. The re-ignition time is reduced to the time required to sweep the high voltage.

A “test and commissioning” mode (T&C) describes a method to sweep the total ion current in steps lasting 8 or 16 s, and with 2 or 4 µA current increment. This mode has been used occasionally to establish the current-voltage characteristics of the spacecraft.

Finally, the instrument features a technical mode (TECH) for low-level commanding.

Start-up (STUP): The description of modes would be incomplete without the start-up. Before emission can take place, the ion emitter must be heated. Depending on the ambient temperature it takes about 12 to 20 minutes to reach a temperature inside the emitters which is sufficient to ignite the ion beam. The period from the beginning of the heating until a few seconds after the ignition of the beam is defined as start-up period. Whenever ASPOC is commanded into a mode involving ion beam emission, the instrument begins a start-up cycle for an ion emitter. Note that within this period the "instrument mode" reported in telemetry is already according to the commanded target mode, whereas there is no ion emission during start-up yet.

3. ASPOC DATASETS IN THE CLUSTER ACTIVE ARCHIVE

The ASPOC Datasets in the Cluster Active Archive (CAA) have been defined as follows.

IONC: This data product contains the ASPOC ion beam current at a sampling interval of ~0.5 s.

IONS: This product resembles snapshots (samples of 8.25 s duration collected every 128.8 s) of the ion beam current with a sampling interval of ~0.033 s. This dataset is useful to check for any current fluctuations in the beam, and to trace the current profile during an ignition of an ion emitter or a shut-down.

STAT: This product provides comprehensive status information of the instrument at 5.15 s (for some parameters, 10.3 s) resolution. The status information includes:

- Operating mode, including emitter start-up status and cleaning: In both of these states the beam current deviates significantly from the nominal current.
- Emitter identification and emitter module identification: Each instrument carries eight emitters bundled into two modules with a common high voltage system within a module. Both emitters and modules may exhibit individual characteristics and performance, which may have an effect on the value and temporal behaviour of the beam current.
- Anomaly flags: These flags give the reason for an anomaly, for example failure of ignition of an emitter.
- Ion beam energy: The voltage applied to the emitter is equivalent to the energy of the ions in the beam.
- Total ion source current: The current delivered by the high voltage supply into the emitter will be higher than the emitted current if internal losses are present.
- Heater current: The current drawn by the heater element associated with an emitter.
- Heater voltage: The voltage applied to the heater element associated with an emitter. Voltage and current together can be used to calculate not only the electrical power but also the temperature of the heater element. From this temperature, the temperature of the emitter tip can be derived.
- Temperature of the ion source module: This parameter contains the ambient temperature of the emitter module. The temperature of the emitter tip shows a strong dependence on the heater temperature, but also some influence of this ion source module temperature.
- Raw spacecraft potential received on board from EFW: This parameter mirrors the spacecraft potential data delivered by the instrument EFW to ASPOC on board the spacecraft. It differs from the EFW data product in the archive with respect to timing.

CMDH: This product contains the telecommand history, with the commands being time stamped with on-board execution time by the instrument ASPOC. The internal delay of command execution may reach one minute. Included parameters are the telecommand code, the command counter, command mnemonic, description, and parameter (if any).

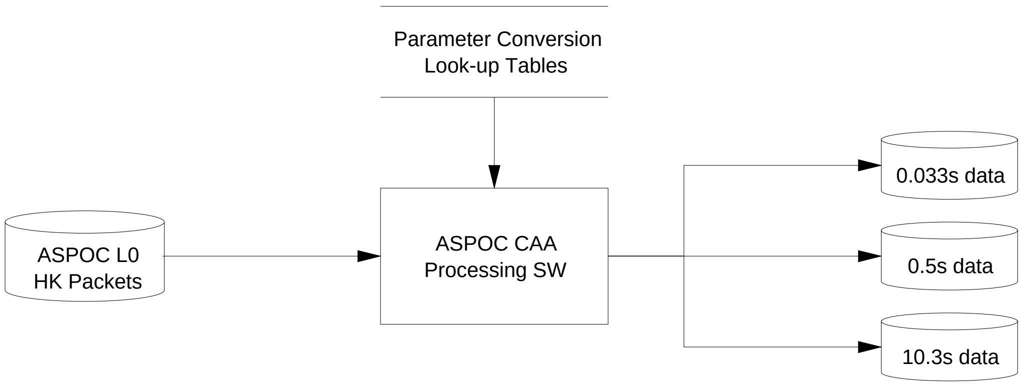

Fig. 3. ASPOC CAA data processing chain.

CAVEATS: This product contains detailed information on the status and quality of the ion emission (see the description of quality levels):

- Time span; the time span is driven by mode changes, e.g., ion beam on or off, emitter changes and resulting quality variations.
- Mean quality level during given time span
- Minimum quality level during given time span
- Maximum quality level during given time span
- Comment; a textual description associated with the average quality level value.

4. DATA PROCESSING

The processing software operates from the ASPOC housekeeping data extracted from the Cluster Raw Data Media as shown in Fig. 3. The data sets are split based on time resolution and will be delivered in ASCII (Cluster Exchange Format, CEF) files. No specific software is required for the end user. Line plots are used to visualise the ASPOC products.

The caveat information consists of an automatically generated part and a manually generated part. The manual caveats are added to the data set after inspection of the data produced in the batch process using dedicated visualisation software. The automatically generated caveats shall help the user to assess the quality, i.e. stability over time, of the controlled spacecraft potential. The production software derives a quality parameter from the total current consumed by the ion emitter and the emitted ion current.

5. DATA QUALITY LEVELS

The quality of spacecraft potential control is described by the absolute value of the potential and its stability in time. In the nominal mode of operation, the instrument is set to output a constant current into the ion emitters (so-called "total current"). If internal loss currents can be neglected, the emitted ion current is also constant and the resulting spacecraft potential has maximum stability with the intended value. If loss currents are present, the emitted ion current is the difference between the total current and the loss current, and will start to fluctuate in antiphase to the with the variations of the loss currents. Table 1 summarises the definition of the quality levels. There are two main reasons why the total current may differ from the ion beam current: a) an internal (ion) current from the emitter tip to the extractor electrode, b) another loss current from high voltage to ground. The quality of the emission is derived from the total current and the emitted ion current. There are new entries whenever the instrument mode changes, or when the commanded emission current changes.

Table 1. Quality level definition

Quality Flag	Current Conditions	Ion Emission Quality
1	$I_{beam}/I_{total} > 0.97$	Excellent
2	$0.92 < I_{beam}/I_{total} \le 0.97$	Good, almost completely stable
3	$0.75 < I_{beam}/I_{total} \le 0.92$	Moderate fluctuations
4	$0.30 < I_{beam}/I_{total} \le 0.75$	Substantial fluctuations
5	$0.00 < I_{beam}/I_{total} \le 0.30$	Severe variations
8	$I_{total} \ge 20$ μA AND $I_{beam}/I_{total} \ge 0.50$	Cleaning
9	$I_{beam} = 0.0$	No emission

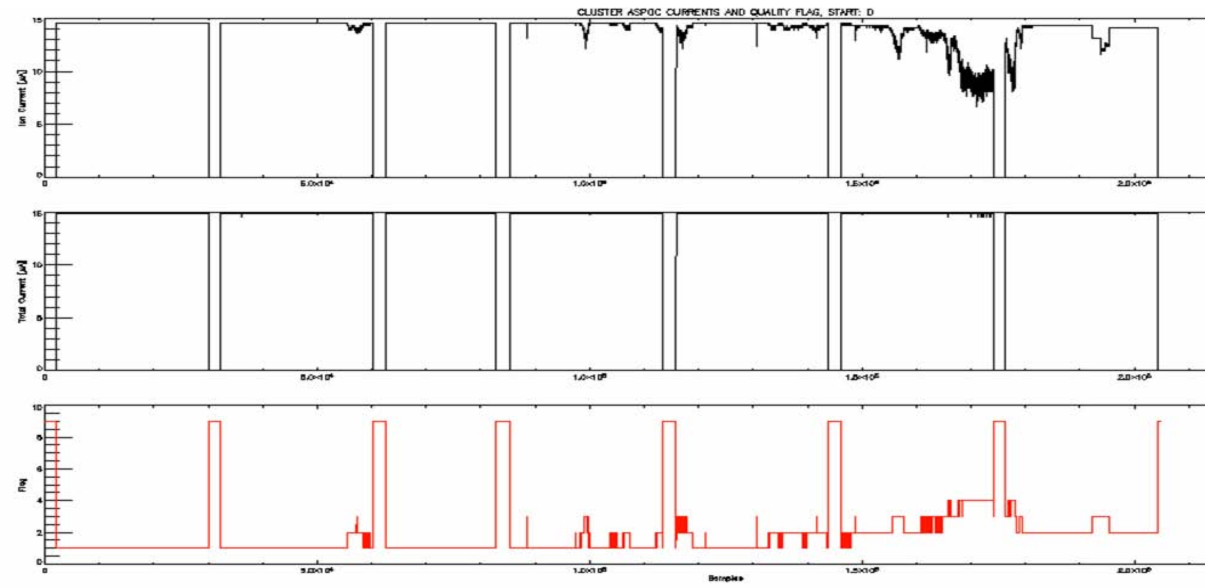

Fig. 4. Sample data plot

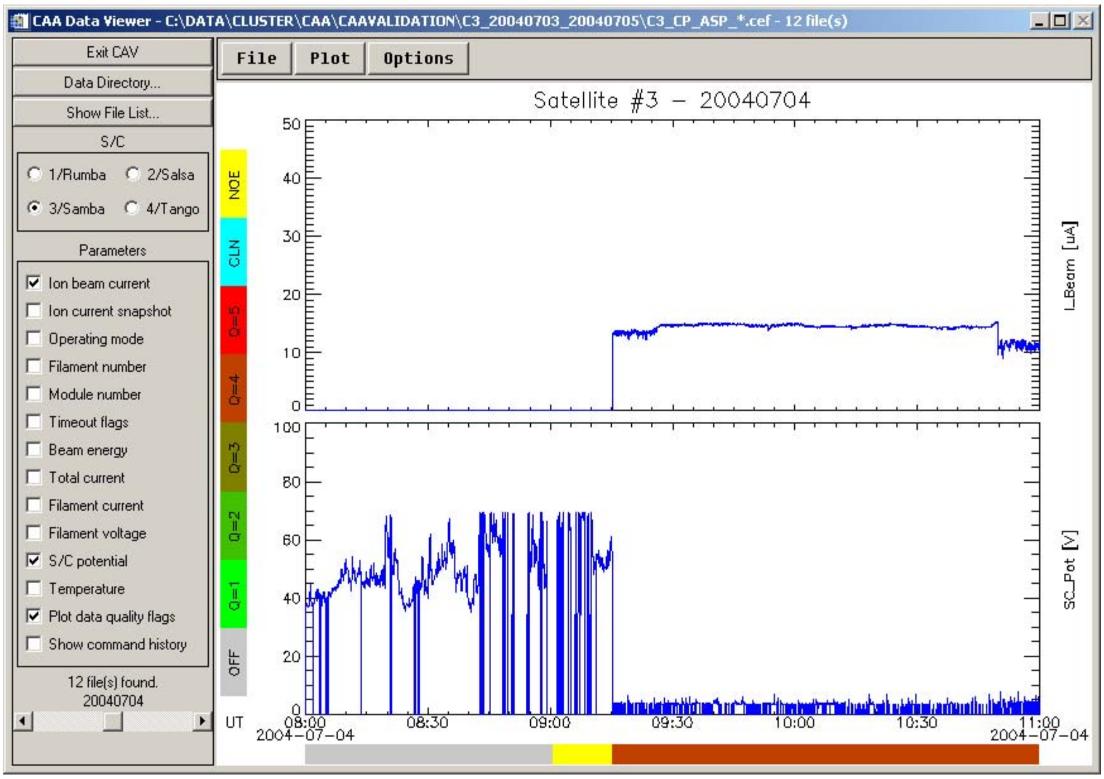

Fig. 5. CAA data validation software display

Fig. 4 shows a collection of 7 operations of ASPOC. The commanded total current (middle panel) is constantly at 10 µA. The beam current (top panel) should coincide with the commanded current, as in operation number 1 and 3, but actually it can be decreased due to temporary internal losses, which happens most prominently in operation number 6. The instantaneous quality flag (bottom panel) accordingly increases to higher (=worse) values during operation 6.

6. QUALITY CONTROL PROCEDURES

Quality control of the archived data includes visual inspection of plots produced from all data products, and spot-checks of the data products. Software has been developed to visualize the data products in combined displays, which facilitates the detection of inconsistencies and anomalies. Data products will be checked in many aspects including the correlations between:

- ion current and spacecraft potential
- ion current and total current flowing into the emitter
- currents in the emitter system and derived quality flag
- ion current data products at different time resolutions
- instrument status and ion emission

Some of these checks can be carried out by the production software and raise warning messages. The other checks will be carried out manually/visually. Fig. 5 shows a display of the ASPOC validation software. It allows to browse through the database of preliminary CEF files. Check boxes allow to select relevant parameters. Plot options and scales can be set automatically or interactively.

If an anomaly related to the processing software is found, the production will be stopped, and new versions of data products will be generated after correction. Anomalies attributed to instrument performance will lead to new caveat entry.

7. CURRENT STATUS AND PLANNING

At the time of writing (September 2005) the data for the first half of 2001 have been submitted to the Archive, based on the definitions reviewed at the CAA Implementation Review in Spring 2005. The ASPOC CAA data production software is operational, and the data validation software has been completed, and is currently undergoing verification testing. The deliveries of the data sets to the Archive are expected to be on the agreed schedule, whereby the manually created caveat information will drive the production schedule.

8. REFERENCES

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