Calibration Report of the **ASPOC** Measurements in the Cluster Active Archive (CAA)

Prepared by

Klaus Torkar

1 Introduction

The instrument ASPOC (Active Spacecraft Potential Control) controls the electric potential of the Cluster spacecraft by means of an ion beam. This modification of the charge balance improves the plasma measurements on board. Beneficial effects have also been observed for the electric field measurements by double probes (EFW). Comprehensive knowledge about the status of the instruments including the ion beam current is necessary to correctly interpret spacecraft potential data.

This document describes all calibration and cross-calibration activities related to the ASPOC instruments.

2 Instrument Description

In order to control the electrical potential of the spacecraft, the ASPOC instruments incorporate liquid ion metal sources to emit a beam of positive indium ions (115 amu) at energies of about 6 to 9 keV and currents up to about 30 µA. Typical currents applied in the mission were between 10 and 20 µA. As a result of the equilibrium between the relevant currents of photo-electrons generated at the spacecraft surface, plasma electrons from the environment, and the ASPOC ion beam current, the spacecraft potential will be clamped to a low positive value. Figure 1 shows a sketch of the operational principle. Small residual variations stem from the collection of ambient electrons, and any long-term trend of the photo-emission either due to Solar activity or spacecraft surface materials (see e.g. Torkar et al., 2008). Due to the high energy of the emitted ions their escape is independent of the spacecraft potential, an accurate knowledge of the energy is not required.

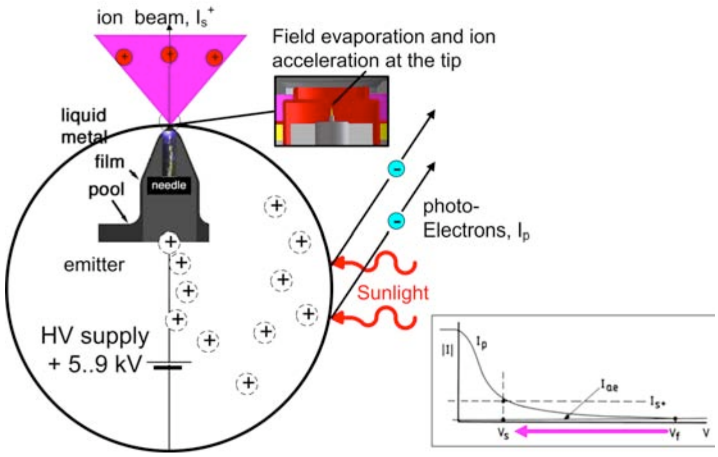

Fig. 1. Sketch of operational principle (after Torkar et al., 2008)

The most important parameter of ASPOC is the current of the ion beam, which is measured by a straightforward monitor built into the ASPOC electronics. The ion beam is unobstructed and deviations between the net outgoing ion current and the measurement can be excluded by analysis. A full description of the instrument can be found in Torkar et al. (2001). The effect of ASPOC is directly visible in the spacecraft potential measured by EFW and appears indirectly as improvements of the plasma measurements of electrons (by PEACE) and ions (by CIS), as described e.g. by Torkar et al. (2005). These potential and plasma effects are topic of cross-calibration activities.

3 Measurement Calibration Procedures

3.1 Calibration

The main parameters measured by ASPOC, the methods of measurement and their calibration are summarised below.

- The emitted ion current
    - This current is measured by a current monitor (resistor and associated analogue-to-digital converter placed directly between ground (i.e., spacecraft structure) and the ion emitter. Thereby it is ensured that the exact value of the current leaving the ion emitter is captured. Any loss currents inside the emitter system are irrelevant for this measurement. It can be shown by analysis that there is also no current path from emitter to structure within the instrument which could lead to an offset in the measurement. There are also no obstructions within the ion beam plume which could "short-circuit" part of the beam.
    - The calibration of the ion beam measurement can be limited to the calibration of the electric beam monitor circuit. This calibration has been performed on all boards.

- The total current generated by the high voltage power supply
    - This current is the sum of the emitted ion current and any additional loss currents internal to the ion emitter. It is useful for monitoring the health of the ion emitter, but there is no direct relation with the spacecraft potential effect. This current is measured by a current monitor between the ion emitter and the supply.

  - For the calibration of this monitor has been performed in the same way as for the ion beam monitor.
- The extraction voltage for the beam ions
  - The extraction voltage corresponds exactly to the energy of the emitter ions. No bias voltages have been applied. The measurement occurs through a straight-forward voltage measurement behind a resistive divider.
  - For the calibration of this monitor has been performed on all boards.

3.2 Cross-calibration

Cross-calibration activities in the strict sense, i.e. calibration between two independent measurements of the same quantity, are not applicable for ASPOC since there is no second measurement of the ion current. However, the desired lowering of the spacecraft potential is closely related to the beam current, albeit modified by ambient plasma conditions. The residual variation of the controlled spacecraft potential is the topic of an ongoing study. Of particular interest is the question whether the estimation of plasma density from the spacecraft potential, which is a convenient method applied to uncontrolled potentials, is still possible when an artificial ion beam comes into the system. The methods rely on the comparison between controlled and uncontrolled potentials (if available) together with independent data on plasma density and the energy distribution of charged particles. Comparisons of potentials can be made by either of the following methods:

- By monitoring the change of potential within a few seconds before and after the ion beam is turned on or off. This method ensures that the plasma conditions with and without ion beam are identical, assuming the absence of short-term variations.
- By statistical evaluation of large quantities of spacecraft potential data under various ambient conditions.
- By comparing the potential of a Cluster spacecraft with an active ASPOC ion beam with the potential of a nearby spacecraft without beam. This method allows to take the variations of ambient plasma conditions into account, however, it assumes spatial uniformity of the plasma within the Cluster spacecraft constellation.

3.3 Supporting Measurements

The calibration of the ASPOC data products, mainly the ion beam current, does not require supporting measurements.
However, various measurement sets are involved in the cross-calibration studies of ion currents and spacecraft potential, as described in the paragraph on cross-calibration.

4 Measurement Processing Procedures

No cleaning or de-spiking procedures were necessary for ASPOC data. Caveats have been provided where applicable.

5 Results of Calibration Activities

The analogue ASPOC parameters consist of current and voltage measurements of the ion beam and of housekeeping parameters. The monitors are straight-forward resistors or resistive dividers with associated analogue-to-digital converters. The calibration has been performed on all boards with the result that the deviations from the nominal values were smaller than the digital resolution of the monitors. As a consequence, the calibration curves for all ASPOC instruments are identical.

- The emitted ion current
  - The deviations from the nominal values has always been smaller than the digital resolution of the monitor which was just 8 bits or 0.2 µA per digit. As a consequence, the calibration curves were identical for all ASPOC instruments.
- The total current generated by the high voltage power supply
  - For the calibration of this monitor has been performed in the same way as for the ion beam monitor. The digital resolution is 0.4 µA per digit, and the calibrated variations were again smaller than the resolution.
- The extraction voltage for the beam ions
  - For the calibration of this monitor has been performed on all boards, again to the result that individual deviations were smaller than the digital resolution of 40 V per digit.
- Heater voltage, heater current, and other housekeeping parameters
  - The monitors for these housekeeping parameters have been calibrated on board level. The knowledge is of secondary importance.

6 Results of Cross-Calibration Activities

The residual variation of the controlled spacecraft potential is the topic of an ongoing study. Figure 2 after Torkar et al. (2008) illustrates that the potential resulting from a constant ion current still shows a small fraction of the variations in the uncontrolled case, which is driven by plasma conditions. Knowledge of the ASPOC ion beam is not only necessary to correctly interpret spacecraft potential data, but can also be used to attempt the derivation of plasma density from the potential even though the potential is under control.

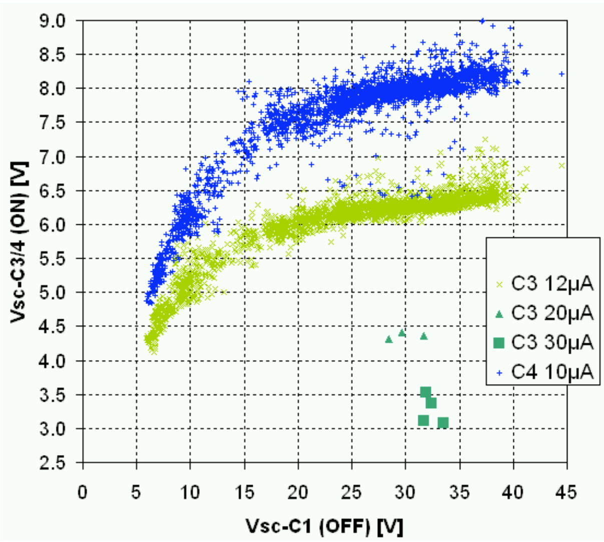

Fig. 2. Correlation of simultaneously taken data from controlled (Cluster 3 and 4) and uncontrolled (Cluster 1) spacecraft; from 21:10 to 24:00 UT on 21 March 2001

First results indicate that persistently "quiet" plasma conditions lead to the best correlation between controlled and uncontrolled potential and thus allow to use similar methods for plasma density estimations. The situation becomes more difficult when the effects of variable plasma temperature have to be compensated. Also the emission of secondary electrons from the spacecraft surfaces after bombardment by energetic ambient plasma particles may have noticeable effects on the controlled spacecraft potential which have to be taken into account in these cross-calibration activities.

The study of the long-term trend of the Cluster spacecraft potential has been included in the work by Pedersen et al. (2008). While this paper deals with the spacecraft potential in general, Torkar et al. (2008) concentrated on long-term trends under conditions when ASPOC was active. One of the results shown in Fig. 3 refers to a decreasing trend of the controlled potential over four years which largely but no fully coincides with the decaying part of a solar cycle. Note that the plotted quantity labelled spacecraft potential is the voltage difference between the spacecraft body and the EFW probes. The exact value of the potential with respect to the ambient plasma includes an additional voltage drop which depends on local effects around the probes.

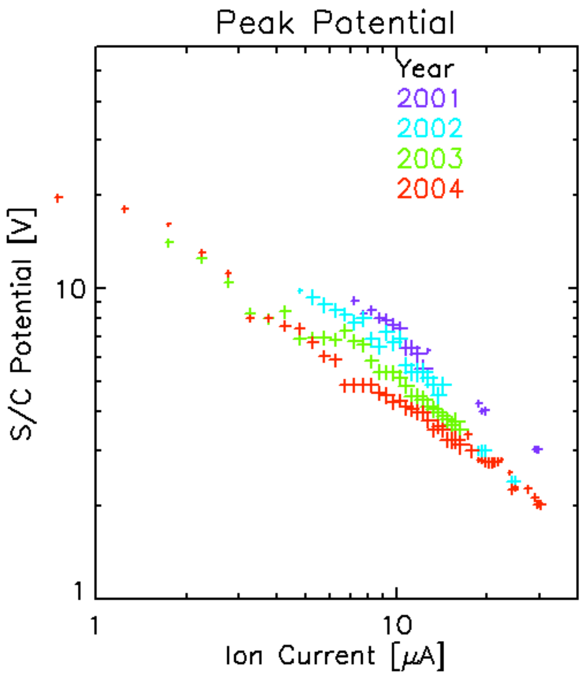

Fig. 3. Variation of peak occurrences of spacecraft potential on Cluster 3, as a function of ion beam current, after Torkar et al. (2008).

7 Summary

The straight-forward construction of the ASPOC current and voltage monitors as well as the measured good linearity allowed to reduce the calibration activities of ASPOC to a minimal level. The absence of further deviations can be shown by analysis.

Cross-calibration between the emitted ion current and the controlled spacecraft potential is inherent to the work principle of ASPOC. Studies to elaborate further on residual variations of the controlled potential have started. First results indicate that certain plasma conditions are favourable to allow the reconstruction of the uncontrolled potential.

8 References

- Pedersen, A. B. Lybekk, M. André, A. Eriksson, A. Masson, F.S. Mozer, P.-A. Lindqvist, P.M.E. Décréau, I. Dandouras, J.-A. Sauvaud, A. Fazakerley, M. Taylor, G. Paschmann, K.R. Svenes, K. Torkar, E. Whipple, Electron density estimations derived from spacecraft potential measurements on Cluster in tenuous plasma regions, J. Geophys. Res., 113 (A07S33), doi:10.1029/2007JA012636 (2008).

- Torkar, K., W. Riedler, C.P. Escoubet, M. Fehringer, R. Schmidt, R.J.L. Grard, H. Arends, F. Rüdenauer, W. Steiger, B.T. Narheim, K. Svenes, R. Torbert, M. André, A. Fazakerley, R. Goldstein, R.C. Olsen, A. Pedersen, E. Whipple, H. Zhao, Active spacecraft potential control for Cluster - implementation and first results, Ann. Geophys., 19, 1289-1302 (2001).
- Torkar, K., K.R. Svenes, A. Fazakerley, S. Szita, H. Rème, I. Dandouras, M. Fehringer, C.P. Escoubet, M. André, Improvement of plasma measurements onboard Cluster due to spacecraft potential control, Adv. Space Res., 36, 1951-1957 (2005). (doi:10.1016/j.asr.2005.01.109)
- Torkar, K., A.I. Eriksson, P.-A. Lindqvist, W. Steiger, Long-Term Study of Active Spacecraft Potential Control, IEEE Trans. Plasma Sci., 36, 2294 - 2300 (2008) doi:10.1109/TPS.2008.2003134