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Life with MC-SNICS. Part II: Further ion source development at the Keck carbon cycle AMS facility

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Abstract

We report on an ongoing program of improvements to the National Electrostatics (NEC) MC-SNICS ion source at the KCCAMS laboratory at UC Irvine. Recent work has focused on vacuum improvements and on increasing the source output and efficiency. We replaced the extractor and preacceleration assemblies for a threefold improvement in pumping conductance, leading to lower source pressures and quicker startup after sample wheel changes. A switch to spherical ionizers caused a marked improvement in the focusing of the Cs beam, leading to major gains in ion source efficiency and negative ion beam quality. Better confinement of Cs within the new ionizer assembly resulted in lower Cs consumption and a significant reduction in arcing problems.

PACS: 07.75.+h; 29.25.Ni; 29.30.Aj

Keywords: Accelerator mass spectrometry; Ion source; MC-SNICS

1. Introduction

The Keck Carbon Cycle AMS facility at the University of California Irvine (UCI) has operated a 40-sample MC-SNICS source [1] since mid-2002. The MC-SNICS sample changer has performed almost flawlessly for the past three years, but the source itself (Fig. 1) initially suffered from severe problems of arcing, poor serviceability and low output and has been the subject of a major improvement program.

Our initial upgrades [2,3] were primarily aimed at improving reliability and serviceability. A sliding track system was built into the existing power supply rack to support the source and allow it to be rolled back for servicing in situ. The Cs oven and delivery tube were rebuilt to a Lawrence Livermore design [4] so that the delivery line was heated by conduction from the ionizer assembly and was vacuum-insulated throughout. This reduced Cs consumption by about 50% and eliminated a problem of clogging of the Cs delivery tube. Changes to the geometry of the extraction electrode reduced electric fields in the extraction gap and eliminated much of the arcing problem in that region. The sample wheel was moved farther from the ionizer for improved Cs focusing at high currents (typically 2–4 mm, depending on cathode voltage, Cs oven temperature, etc). A cooling line was built into the downstream source flange to trap more stray Cs in the source body, further reducing extraction arcing. The extra cooling also allowed us to replace a wire seal between the source and extractor housing with a more convenient Viton O-ring. Problems of sparking from NEC's aluminum sample wheels at source startup were eliminated via improved cleaning procedures which prevented buildup of insulating aluminum oxide–hydroxide coatings and subsequently by adoption of a new copper and stainless steel wheel design (Fig. 2).

This first set of changes solved most of the reliability problems that initially plagued the source, increased its output and made it much easier to service. More recent work has concentrated on obtaining better vacuum and on further improvements in source output and beam quality.

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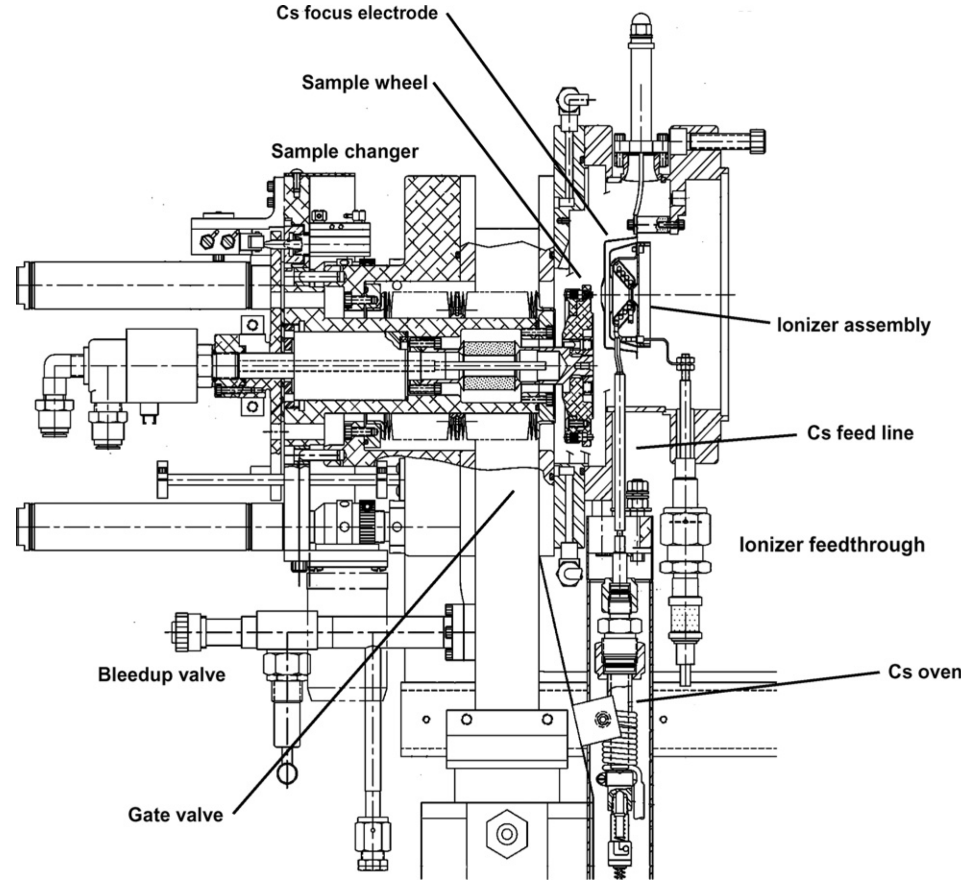

Fig. 1. Unmodified 40-sample MC-SNICS ion source and sample changer. The ionizer assembly is supported by three legs (not shown here) from the same internal lugs as the Cs focus electrode. Major changes made to the UC Irvine source include installation of a new Cs oven and feed line, sample wheel and ionizer assembly, replacement of the Cs focus electrode with an immersion lens at cathode potential and provision of cooling on the downstream flange.

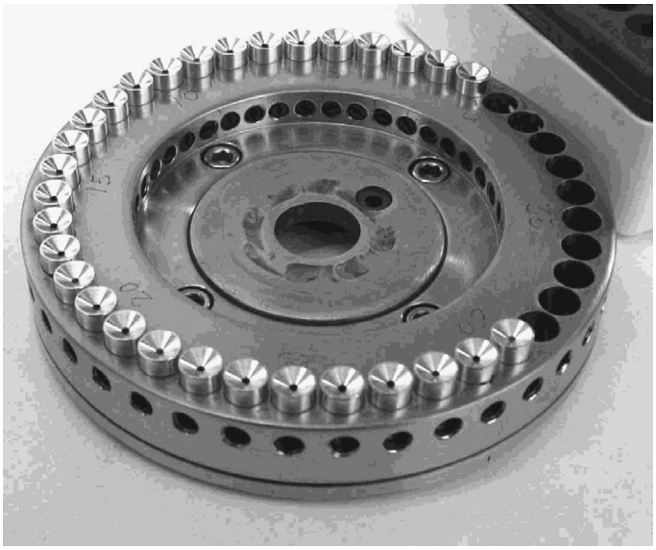

Fig. 2. The UCI wheel for the MC-SNICS source. Sample holders are 6.35 × 12.7 mm cylinders of Al (large enough to be labeled). Graphite is loaded from the front of the sample holder by tamping it into the central 1 mm hole, then pressed by hammering on a piece of drill rod. The sample holders are retained in the wheel by sideways pressure from spring-loaded ball inserts.

2. Vacuum improvements

The standard NEC extraction/einzel lens/preacceleration assembly (NEC #067650) severely limits the pumping conductance between the source and downstream vacuum pumps. In late 2003 we rebuilt the internal extractor electrodes with a more open structure and replaced all aluminum parts with stainless steel for ease of cleaning (Fig. 3). The ratio of the pressures measured in the source sample changer and at the downstream cryopump dropped by about 50%, consistent with an expected doubling of the conductance based on the open area of the new and old designs.

In late 2004 we replaced the NEC preacceleration tube between extractor assembly and the downstream pump cross, with a gap lens built into a larger-diameter insulator (Ceramaseal #17146-02-CF). This was made possible by modifications carried out in 2003: we now support the source from the high voltage rack, so the preaccelerator insulator is no longer a structural member. A full-length internal tubular shield protects the insulator from stray Cs and the larger diameter (12.5 cm inside the shield vs 10 cm for the NEC tube) has increased the conductance of this section by 30–40%.

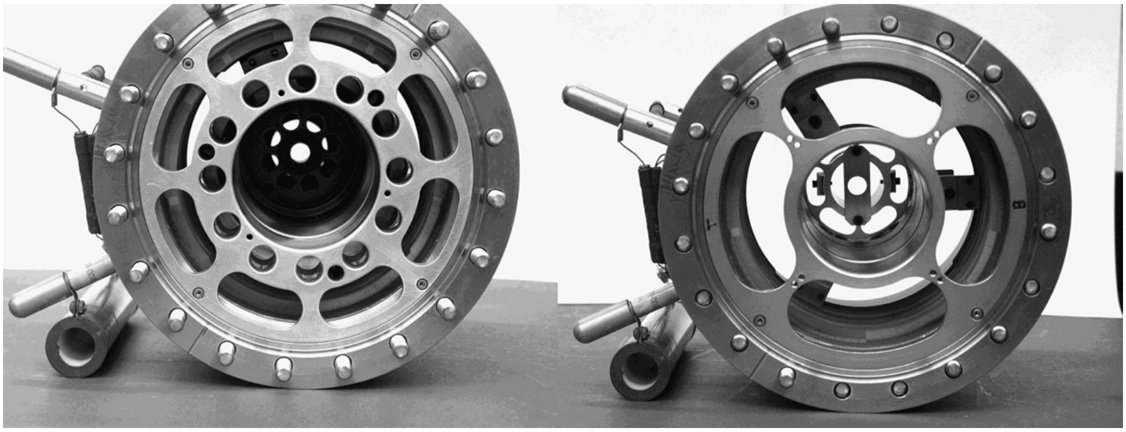

Fig. 3. Old and new extraction assemblies, showing the larger pumping apertures of the new design.

These modifications led to a significant reduction in the pumpdown time required after a sample wheel change. Previously, high outputs could only be achieved after 30–60 min of pumping: turning the ionizer and Cs oven on earlier had little effect. With these changes, the source could be turned on almost immediately after a wheel change.

A final improvement will be to replace the extractor housing for further increases in conductance and improved reliability. The present 12.5 cm ID unshielded NEC external insulator will be replaced by a section of 15 cm beam pipe with new internal electrodes mounted on ceramic posts (Fig. 4). The post insulators are designed to run sufficiently hot to prevent Cs condensation, in contrast to the unshielded ceramic rings in the old extractor housing, which were prone to arcing in the presence of stray Cs. This change has become less urgent because the reduced Cs consumption with new ionizer assemblies (Section 3) has almost eliminated the arcing problem, but the new extractor will provide another 30% increase in conductance and will be easier to service if the need arises.

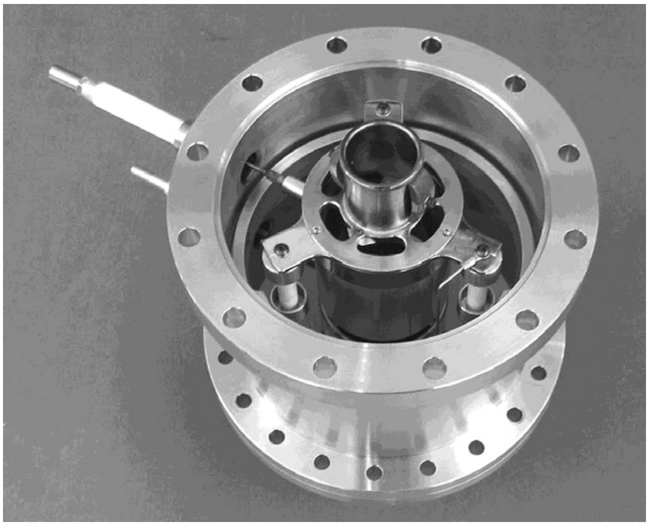

Fig. 4. Third-generation extractor and einzel lens assembly. The electrodes are mounted off an alignment ring welded to the inside of the housing and can be removed as a single unit for cleaning with the housing left in place.

3. Spherical ionizer assemblies

3.1. Spectramat

Spherical ionizers provide inherently better Cs focusing than the standard NEC conical design, because all of the initial Cs trajectories are directed towards a single point at the center of the sphere. This allows for increased source output while maintaining high beam quality (low emittance). In December 2004 we replaced the conical NEC ionizer and housing with a new assembly based on the spherical ionizer (Spectramat/Heatwave #101278A, $R = 0.688$ in.) and electrode geometry used in the CAMS/Lawrence Livermore source [4]. Fig. 5 shows the new assembly mounted on a modified NEC ionizer baseplate. The delivery tube from the Cs oven screws on to a hollow stud and Cs vapor entering the assembly via the stud is confined in a circular gallery between an inner ring and outer shroud. Slots in the ring and a lip on the shroud electrode direct jets of Cs vapor directly on to the hot ionizing surface.

Because the Cs beam is focused on to the sample by the electrode geometry of the ionizer assembly itself, the Cs

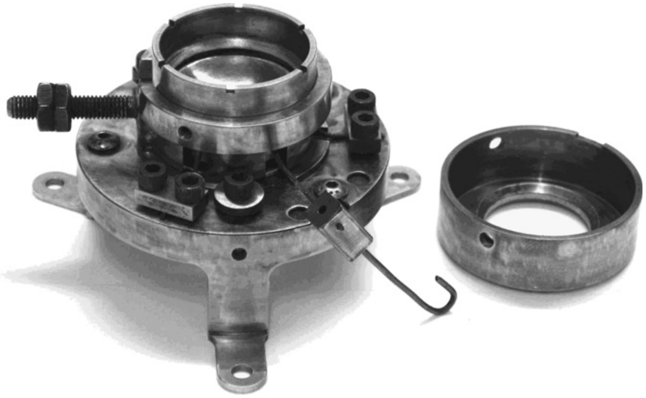

Fig. 5. Spectramat ionizer assembly, with outer shroud removed.

focus electrode of the standard source is no longer required. This electrode and its power supply were removed and the mounting points were used with longer insulators to support an immersion lens – an aperture at cathode potential mounted 3 mm in front of the sample wheel. This lens plate serves several functions. It reduces the radiant heat load from the ionizer on the sample wheel; it preserves cylindrical symmetry (and thus improves the Cs focus) by preventing the Cs beam from "seeing" the top edge of the sample wheel and protruding sample holders adjacent to the one being sputtered; and the aperture focuses the negative ion beam to pass cleanly through the central hole in the ionizer. The new geometry also provides improved local pumping and improved voltage holding capability in the critical central region of the source, since clearances between electrodes are increased.

These changes have allowed us to run routinely with C^- outputs of 120–150 μA. Measurement quality has been maintained and even improved: precisions/accuracies of 2–3‰ in $\Delta^{14}C$ are achieved fairly routinely with graphite from several laboratories. Cs consumption dropped significantly, perhaps by as much as 30%, due to the better confinement of the Cs within the machined housing; and as a result, problems of arcing due to stray Cs in the extraction region are now extremely rare.

In addition, we have found that the well-focused Cs beam sputters a remarkably straight-sided flat-bottomed hole into the sample, so that source output is maintained until essentially all of the sample material is consumed. On large (1 mg C) test samples run to extinction, we have detected over 10% of the ^{14}C atoms present in the samples. Given the measured 44% transmission (C^+/C^-) of our spectrometer, this is indicative of source efficiencies above 20%. Similar or even higher efficiencies have been obtained with the CAMS/LLNL source [4,5], which employs a similar Cs geometry. Importantly, our source efficiencies are 10–15% for samples as small as 5–10 μg of carbon, indicating that high precision (<1%) measurements on ultra-small samples are possible [6].

An unexpected bonus is that under the new geometry, much more light from the ionizer is reflected from the cathode down the beamline than previously. With these increased light levels plus an earlier modification that removed a restrictive collimator in the extraction assembly, a simple low-magnification source viewing system (a 20× magnification Leica NA720 autolevel mounted on a viewing port in the injection magnet) allows the position and shape of the Cs spot to be monitored while the source is running.

3.2. NEC

The Spectramat setup is now our standard configuration, but we have also tested spherical NEC ionizers. The two ionizers are built very differently: the Spectramat heater is potted in alumina insulation, whereas the NEC design uses a bead-insulated heater wire coiled inside two formed sheet tantalum shells. The solid Spectramat unit is therefore quicker to outgas, but an advantage of the NEC system is that the ionizer can be disassembled and modified or repaired. NEC donated two spherical ionizers of different radii to the project and we also built jigs that allowed us to deform the front face of the standard conical ionizer (Fig. 6) to investigate different geometries.

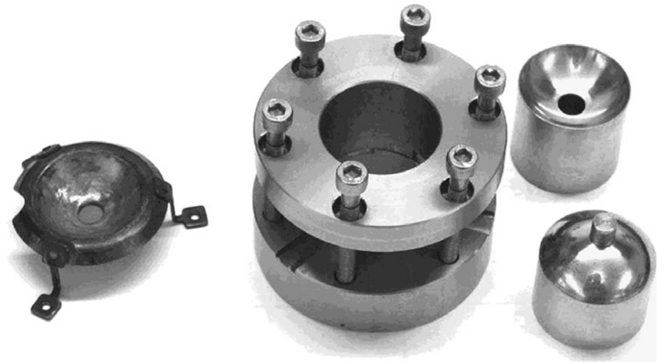
Fig. 6. Clamping ring and upper and lower jigs for deforming the front surface of an NEC ionizer (shown at left) from a conical to a spherical shape.

As a starting point we enlarged the apertures in the NEC ionizer shroud and the Cs focus electrode and used these with a spherical NEC ionizer ($R = 0.688$ in.) to produce a geometry similar to that used in [7]. (Experiments with a 1 in. radius ionizer were unsuccessful, as the focal point for the Cs was much farther from the ionizer than the range of longitudinal adjustment of the sample wheel could accommodate). We also added a cathode immersion lens and Fig. 7 shows how this was mounted off the Cs focus electrode. This configuration produced good Cs focusing and C^- currents of up to 150 μA. However, it seemed

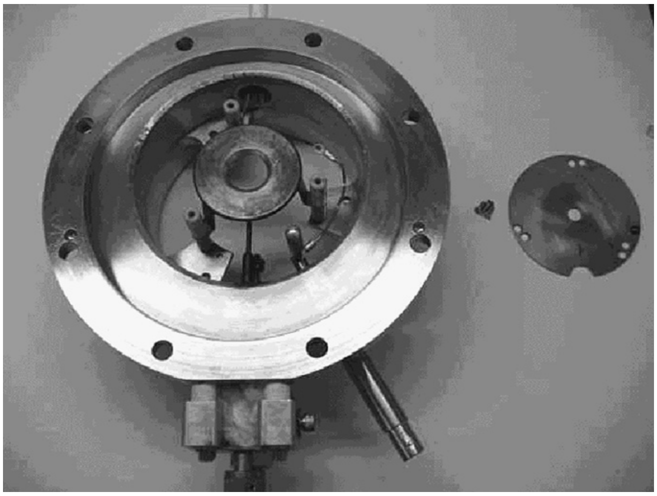
Fig. 7. Cs focus and immersion lens geometry for use with an NEC spherical ionizer, based on a design by Weisser et al. [7]. Extra insulators are used to mount the immersion lens plate (at right) from the Cs focus electrode, which has been modified with a larger diameter aperture.

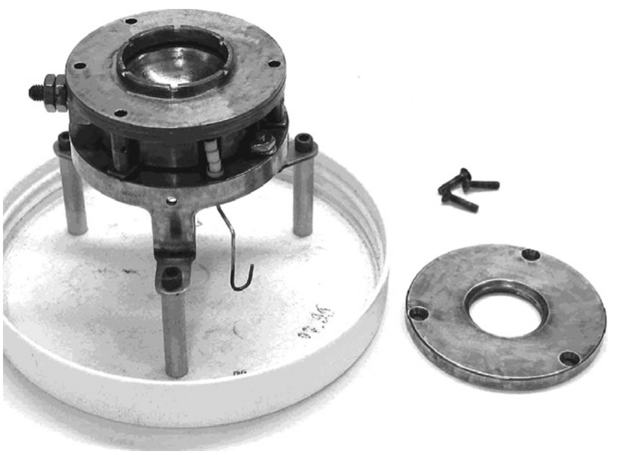

Fig. 8. NEC spherical ionizer assembly with a machined heat shield and Cs gallery. The geometry of this design is similar to the housing for the Spectramat ionizer and no Cs focus electrode is required.

unnecessarily complex, especially since the optimum Cs focus was achieved with the focus electrode almost at ionizer potential (as expected, given the similarity of the overall geometry to that of the Spectramat assembly).

We therefore built a new assembly where NEC's pressed tantalum shroud around the ionizer was replaced with a machined Cs gallery similar to that used with the Spectramat ionizers and again eliminated the Cs focus electrode. Fig. 8 shows this assembly with the cover of the Cs gallery removed. After some optimization of the design of the lip that deflects the Cs vapor on to the ionizing surface, currents of 130–150 μA of C^- and a Cs beam spot well matched to the sample size were obtained. Clearly, similar performance can be obtained from ionizers of similar geometry from either manufacturer, regardless of the details of construction.

4. Source performance

Typical source operating parameters are:

Cathode voltage	−8 kV
Extraction	−11.5 kV
Focus (einzel) voltage	−1.5 kV
Source bias	−36 kV
Cs oven heater voltage	69 V (21 W)
Cs oven temperature	155–160 °C
Ionizer current and voltage	14 A, 8 V (Spectramat) 23 A, 5 V (NEC)

The source routinely delivers up to 150 μA of C^-, sufficient to measure a wheel of 40 close to Modern samples to 2–3‰ in less than 24 h. Startup after a sample wheel change takes less than one hour and a full source cleaning (required every few weeks, depending on how frequently the source is run) can be completed in 3–4 h including the bakeout time required for achieving good vacuum.

5. Retrofitting a 40-sample source

The alterations made to the ion source body itself in 2003 (the new Cs feed and the provision of extra cooling) were carried out on a set of flanges purchased unassembled from NEC. These were modified in the UCI Physical Sciences machine shop and the source body was then welded up. Recently, the shop upgraded the original ion source body purchased from NEC as part of the AMS system in 2002. This demonstrated that an existing (i.e. preassembled) 40-sample ion source body can be successfully retrofitted.

6. Retrofitting a 134-sample source

Remachining the 134-sample version of the MC-SNICS source to retrofit these changes would be significantly more difficult due to the larger size and asymmetry of the source body. It may be possible to implement the cooling and O-ring modifications to the downstream flange using a computer controlled (CNC) mill, but unfortunately, the point where the existing Cs feed enters the source body is almost impossible to access once the body of the 134-sample source is assembled. However, since the new ionizer geometries do not require a Cs focus electrode, ionizer heater power could be brought into the source via the former Cs focus feedthrough, thus freeing up the ionizer feedthrough for potential use as a new Cs input port. In principle, then, these changes could probably be retrofitted to the larger ion source as well.

7. Summary

Several major changes were made to our MC-SNICS ion source over the past two years. We replaced the extractor and preacceleration assemblies for a threefold improvement in pumping conductance, leading to lower source pressures and quicker startup after sample wheel changes. The standard NEC conical ionizer and Cs focus electrode were replaced with a new spherical ionizer assembly and negative ion immersion lens at cathode potential. This new geometry routinely delivers up to 150 μA of C^- at 8 kV cathode voltage and source efficiencies of over 20% have been determined for 1 mg carbon samples run to extinction. Efficiencies on 5–10 μg samples are greater than 10%, sufficiently high that the radiocarbon content of such small samples can be now be measured precisely. The entire suite of changes applied to the UCI ion source, including remachining of the ion source housing itself, have been retrofitted to a 40-sample MC-SNICS and could probably also be implemented on the larger 134-sample source.

Acknowledgements

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