Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research B 259 (2007) 62–65
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

The status of SMCAMS after recent upgrades ☆

Yonghao Liu *, Shengli Wang, Deming Li, Guosheng Chen, Wenhong Jia, Maobai Chen

Shanghai Institute of Applied Physics, Chinese Academy of Sciences, P.O. Box 800-204, 201800 Shanghai, China

Available online 4 March 2007

Abstract

In this paper, we report on some recent upgrades to SMCAMS (the Shanghai Mini-Cyclotron based Accelerator Mass Spectrometer): mainly a new multi-cathode Cs sputter negative ion source and a new control system. An emergent fundamental problem of instability of the magnetic field with mini-cyclotron AMS will be discussed along with our solution. Given the recent successes of the smaller tandem-based AMS systems, at present it is unlikely that this instrument will find widespread use in the AMS community.

Keywords: SMCAMS; Ion source; Control system; Cyclotron

1. Introduction

At AMS-8, we reported on our first real radiocarbon measurements, in which more than ten unknown ^{14}C samples were dated and cross-checked. The intercomparison of these results with the ones from Arizona University and Peking University showed agreement to within one to two sigma, A precision of ~1% obtained for samples as old as 2000 yrs is relatively satisfactory, compared to the performance of the more common tandem-based AMS facilities [1,2].

Since then, continuous efforts to improve SMCAMS (Fig. 1) have proceeded. A series of upgrades has been carried out in the last few years, mainly building a new multi-cathode Cs sputter negative ion source and establishing a more robust control system. In this paper, the recent upgrades will be introduced, as well as its general AMS performance after these upgrades. Additionally, an emergent fundamental problem with mini-cyclotron AMS, instability of magnetic field, will be discussed along with our solution.

2. Recent upgrades

2.1. The new multi-cathode Cs sputter negative ion source

A pneumatic 24-cathode Cs sputter negative ion source with a rotary operating mode has been developed to replace the original 8-cathode structure which operated in a 'push–pull' mode. It allows us to not only accommodate more samples but also enables unattended measurements.

The new ion source (Fig. 2. shows its multi-cathode device) has a similar sample-indexing and positioning mechanism as MC-SNICS (Multi-Cathode Source of Negative Ions by Cesium Sputtering) made by NEC (National Electrostatics Corporation, Middleton, Wisconsin), but with some differences. One of the most desirable features is the smaller sample cathode geometry as no sample actuation is needed for changing samples, thus keeping the size of the sample wheel with 24 sample positions even smaller than the carousel with only eight cartridges in the original source. The weight of the whole structure is thus kept as light as possible, which is very advantageous for the operation of this vertical ion source because of our upright injection line. The surface diameter of the pressed samples in the Al sample holder is reduced from 2 mm to 1.5 mm, which might benefit small sample analysis. The sample holder is offset relative to the optical axis of the source so that a simple rotary motion of the cathode wheel can move

☆ This work is supported by Chinese Academy of Sciences.
* Corresponding author. Tel.: +86 21 5955 4751; fax: 86 21 5955 3021.
E-mail address: Liuyonghao@sinap.ac.cn (Y. Liu).

0168-583X/$ - see front matter
doi:10.1016/j.nimb.2007.01.302

Fig. 1. The photograph of the Shanghai Mini Cyclotron based AMS facility (SMCAMS).

individual samples into beam position. The deionized water-cooled cathode wheel rotates coaxially with the exterior ratchet wheel driven by the pneumatic system. The pneumatic system executes cathode changing, sample positioning and cathode wheel retraction for replacement and is locally controlled by an 8031 SCM (Single Chip Micyoco), which further communicates with the host computer via its RS-232 port. Through an involatile PROM chip design, the sample number at the beam position can be recalled at anytime. The gate valve is used to protect the vacuum in the cesiated area while replacing the cathode wheel.

The original source and extraction assembly in the old 846 model ion source were kept intact. The beam optics in the ion source are almost unchanged. Following examination of the cesium spot, the cathode wheel structure was modified to match the Cs focusing spot of the spherical ionizer to the center of the sample holders.

Ion beam currents of 80 μA could be easily extracted without observable emittance deterioration. The time needed for changing the sample to the next one is less than 4 s. The sample-positioning precision and reproducibility have been verified by both isotopic ratio measurements and a specially designed mechanical calibration process. In the latter, we concluded that the sample-positioning precision and reproducibility is within 0.05 mm.

2.2. The new control system

It was realized that the previous centralized control system was no longer able to meet the requirements for reliable and precise AMS measurements because of its poor reliability and stability. The newly established control system is based on a multi-drop RS-485 network, in which all the commands and data are transmitted through a shielded pair twist (BUS). Many devices are controlled through the high-speed communications (115,200 baud rates) between the host computer (an industrial PC) and various DA&C modules located near the devices. The power supplies, floated at −15.0 to −17.5 kV (the ion source), are controlled remotely via digital and analog fiber-optics link. The 8031 control unit, working at a different baud rate, communicates with RS-485 bus via a baud rate converter. The timing of the beam collection or ^{14}C counting is controlled through a data link between the bus and the multi-channel pulsing discriminator card. The control software running under Window98 was compiled with Inprise Delphi 5.0, which manipulates the routine operation of the machine and the unattended sequential accelerations/measurements. The data acquisition PC records the measurement results in a binary file and an offline data analysis software was developed to yield final results (yrs BP or pMC and measurement precision) based on the measurements of $^{14}C/^{13}C$ ratios of the standard, unknown and blank samples in the same run.

Meanwhile, five old-fashioned power supplies whose stabilities are of critical importance to measurement precision have been replaced by Glassman High Voltage (High Bridge, New Jersey) products. The old electronic square-wave generator (with its low frequency precision) often malfunctioned and was replaced by an Angilent arbitrary waveform generator with a frequency precision of 1 μHz, controlled via a RS-232 connection. However, we have not been able to redesign our triangular wave RF power

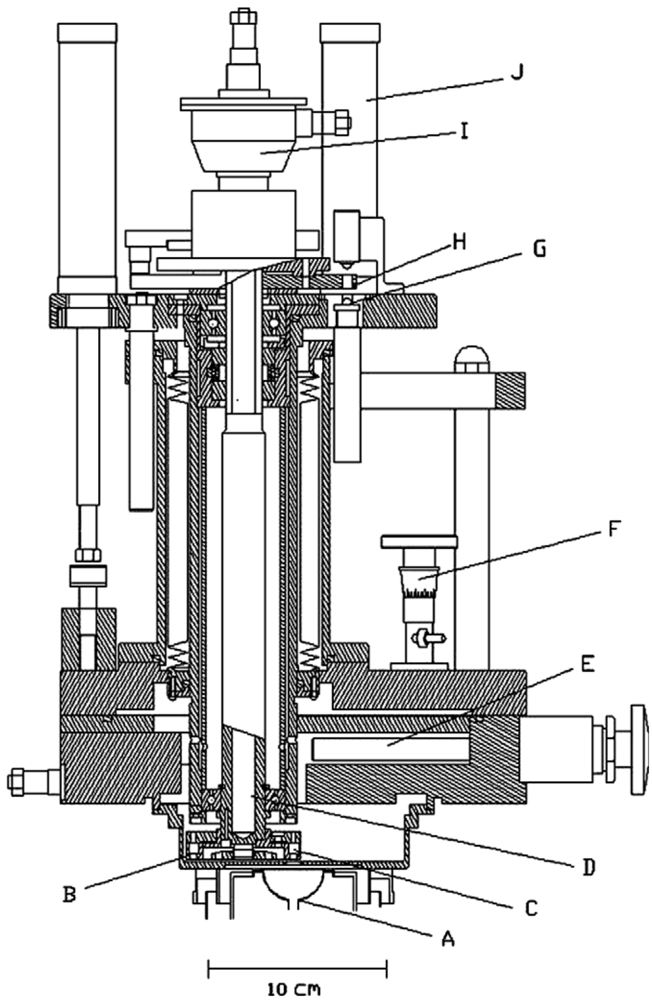

Fig. 2. Schematic side view of the SMCAMS multi-cathode device. A: ionizer; B: cathode wheel; C: sample holder (−15.0 to −17.5 kV); D: rotary shaft; E: gate valve; F: pinhole valve; G: positioning bolt; H: ratchet wheel; I: coolant head and J: gas cylinder.

supply. At each frequency, there exists a non-linearity between its output voltage and control input, so its output must be approached slowly to the preset value by the software, which lenghtens the switch time between different ion species to 5 s.

These upgrades have been used for routine measurements and have resulted in better reliability and stability, greatly reducing the number of spikes in the isotope ratio measurement.

3. Performance

Due to the lack of sample preparation means at the laboratory, measurement of $^{13}CH/^{12}CH$ ratio of pencil core samples instead of real samples has become a convenient, effective and routine method for us to evaluate the stability and reproducibility of SMCAMS. We measure only $^{14}C/^{13}C$ ratios of samples since the system has a poor transmission for $^{12}C^-$ (<5% from the source to the detector) and more importantly, poor reproducibility of $^{13}C/^{12}C$ ratios among samples, which are heavily dependent on the primary beam current from the ion source [1,3]. Fortunately, $^{13}C^-$ and $^{14}C^-$ have much higher and relatively identical transmissions, ranging from 13% to 17%. The $^{13}CH^-$ (also the pilot beam for $^{14}C^-$)/$^{12}CH^-$ ratios were also very stable and agreed well among the same kinds of sample eventhough the beam intensity of these molecular ions declined rapidly.

Up to now, about 200 unknown samples have been measured for several domestic AMS users, mainly including two geological profiles and about 150 biomedicine samples. Most of the measurement results were satisfactory for the users in accuracy and precision and thus used in their studies [4–6]. However, a recent transmission decrease of 40%, caused by unknown factors, means that at least half an hour is needed to collect 15,000 ^{14}C counts to guarantee a final precision of 1% in the $^{14}C/^{13}C$ ratios of a sample with a Fraction Modern Carbon of 1.

A clean standard and an ancient wood sample (43,000–44,000 yrs BP, as measured at the Peking and Leibniz AMS facilities) were intentionally kept adjacent to one biomedicine sample with high ^{14}C concentration (21.4 Modern Carbon). We had previously measured this sample to have an age of 41,940 ± 900 yrs BP. A re-measured age of 41,200 yrs BP indicates negligible cross-contamination in the new ion source. The machine background of 0.04 cps, corresponding approximately to 0.22–0.30% modern carbon, was based on a large number of measurements lasting for at least an hour under ^{14}C parameters but with the measurement deflector before the $^{14}C^-$ detector turned off [3].

Routine radiocarbon measurements could begin soon although more efforts are still required to optimize the whole system, especially in improvements to the vacuum system and in overcoming some encountered problems unique to mini-cyclotron AMS.

4. Instability of magnetic fields and solution

The magnetic field of the mini cyclotron is kept constant and the measured ions are selected by changing resonance frequency and other electric parameters. However, the frequency response is not a real 'flat-top' on SMCAMS. The beam intensity is reduced by about 10% for a 200 Hz frequency change from the resonance frequency (4.0–5.0 MHz). Magnetic field drift, which will remove the cyclotron from its resonant condition, will inevitably lower beam transmission and, more adversely, affect measurement accuracy. Extensive observations showed that magnetic field drift exists occasionally on SMCAMS, especially in long-term, continuous operations, usually corresponding to a resonance frequency shift in the range of 100–200 Hz in 10 h.

We believe that the temperature drift of the magnet sector is the main cause for the magnetic field drift. In fact, several cyclotron laboratories have reported various kinds of thermal effects on magnets dominating the instable performance of cyclotrons [7,8]. The temperature change of the magnet could lead to field variation by deforming the magnet sector and even the supporting structure in some unfavorable circumstance. As reported, significant field variation could be observed in response to a temperature change of the cooling water in the trim coils of about 4–5 °C. Surprisingly and fortunately, our cooling water system, located in a separate room, was found to be incapable of stabilizing the temperature because of insufficient cooling capacity and abnormal temperature control over long periods. An indicated temperature variation in the range of 4 °C could be frequently observed and, in the summer, even as much as 10 °C from noon to midnight. A new cooling water system, that is capable of stabilizing the temperature within ± 0.5 °C, has been recently installed. The room temperature is strictly controlled within ± 1 °C. According to our observations in the last few months, the drift of the magnetic fields has been reduced to within 50 Hz during a 48 h operation.

5. Conclusions

Unattended measurements, better stability and reliability of the system have been achieved through recent upgrades. The throughput and precision of our machine may be more suited for the measurement of biomedical samples, for example, the measurement of a wheel of 24 biomedical samples to a precision of 1% can be finished within 5 h. However, high throughput measurements with higher precision (<0.5%) for samples less than modern carbon is impeded by its poor beam transmission, which will be a bottleneck for further performance improvement.

Given the recent successes of newer, smaller AMS instruments, it is unlikely that this machine will be copied by another lab in its present status. The performance of SMCAMS cannot presently compete against the commercial small tandem AMS (for example, the 0.5 MeV system from NEC), especially in beam transmission and sample throughput. This is unlikely to change in the near future.

Acknowledgements

Thanks are given to Prof. Fuahu Chen at Lanzhou Uni. and Dr. Hongfang Sun at Peking Uni. for providing us with many geology and biomedicine AMS cross check samples to validate SMCAMS.

References

[1] Maobai Chen et al., Nucl. Instr. and Meth. B 172 (2000) 193.
[2] Weijian Zhou et al., Nucl. Instr. and Meth. B 172 (2000) 201.
[3] Yonghao Liu et al., Nucl. Instr. and Meth. B 160 (2000) 424.
[4] Huagui Yu, Radiocarbon Chronology Study of Zhouyuan Loess in China, Master thesis, Institute of Earth Environment, Chinese Academy of Sciences, 2005.
[5] Huagui Yu, Weijian Zhou, Geolog. Sci. Technol. Inform. 26 (2007) 46.
[6] Huifang Du, Chemical reaction of lead-free gasoline additives MTBE and TBA with biological macromolecules in vivo studied by AMS, Doctoral thesis, Fudan University, 2005.
[7] S. Okumura, K. Arakawa, M. Fukuda, et al., Rev. Sci. Instr. 76 (2005) 033301.
[8] T. Saito, K. Sato, T. Yamazaki et al., Thermal Effects in Stability of Cyclotrons, The First Asian Particle Accelerator Conference (APAC98), March 23–27, 1998, KEK, Tsukuba, Japan.