A fast isotope switching system for high energy ions.

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Introduction.

In accelerator mass spectrometry (AMS), isotopes to be measured are usually injected sequentially into the accelerator for each cycle. In order to achieve fast cycling time, the injector magnet field is held constant and the different isotopes are modulated in energy by floating the beam box at appropriate voltages to maintain the same orbit. This method is commonly known as 'bouncing'. Alternatively, the different isotopes can be injected simultaneously after suitable attenuation of the more intense isotopes following dispersion with a first dipole magnet, and recombination in a second dipole in a configuration known as the Brown achromat. The advantage of this latter - 'recombinator' method[1] is that the different isotopes can be measured simultaneously at the high energy end. In the first method, at the high energy end the different isotopes are either measured in separate Faraday cups if a broad range magnet is used, or by altering the magnetic field for each isotope - which can only be carried out slowly, governed by the magnet settling time. The bouncing scheme used at the lower energy side is impractical to use at the high energy end due to the excessively high voltages required.

The AUSTRALIS (AMS for Ultra Sensitive TRAce eLement and Isotopic Studies) at the CSIRO HIAF laboratory, a microbeam AMS system [2,3], is aimed for applications in the medium to heavy atomic mass region, for which the recombinator technique is not suitable due to the difficulty in rejecting or attenuating intense peaks due to the relatively closer spacing of the orbits, and thus the sequential injection method is the more suitable method. At the high energy end, it is desirable to achieve the same fast 'bouncing' rate as that can be achieved at the low energy end in order to obtain high precision in the isotopic ratio measurements.

High energy fast bouncing.

We have adapted a technique pioneered by Amsel et al.[4] to achieve the fast bouncing rate at the high energy. Originally developed as a convenient means of modulating the beam energy over a small relative interval in excitation function measurements, the method is readily adaptable as an isotope switcher. In this scheme, different isotopes of the same energy are deflected off axis in the orbit plane by varying amounts at the entrance to the magnet and returned to the main axis at the exit by another deflection of the same magnitude in the same plane, as shown schematically in figure 1.

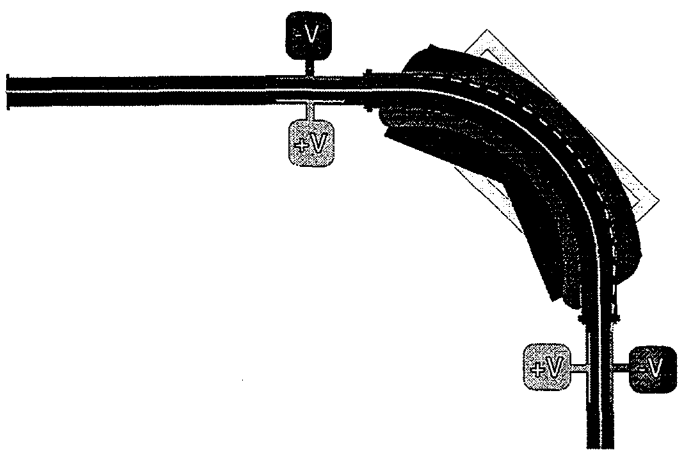

Figure 1. The fast bouncing system at the high energy end consists of pairs of deflector plates at the entrance and at the exit of the high energy magnet, deflecting the beam in the plane of orbit. The voltages are identical for the two sets of plates.

In the AUSTRALIS system, the high energy mass spectrometer consists of a 1.3 metre radius, 90^{o} double focusing analysing magnet designed to enable analyses of elements up to U at 2.5 MV terminal voltage for charge state 6^+. The pole gap is 2.5 cm, and tips are 15 cm wide which is sufficient for the application of this bouncing method. The magnet is followed by two 3 metre radius, 2.5 cm gap, 22.5^{o} bend, spherical electrostatic analysers (ESA's) separated by an electrostatic doublet that focuses the beam at the detector chamber at ~70 cm from the second ESA. The beam can be measured either in a Faraday Cup, ion counter or a gas proportional counter. The electrostatic deflector plates are housed at the entrance and exit ports, and consist of 20 cm long by 5 cm plates separated by 2.5 cm gap. The voltages are supplied by a fast high voltage amplifier (from TREK Inc.) with 10 kV/ms slew rate, driven by a pulse generator.

Results

The system is tested first with a proton beam where the beam energy is varied while maintaining the same magnetic field in the analysing magnet. The magnet was operated with 2 mm slit widths and was first set to pass 3 MeV protons at zero deflector voltage. The beam energy was then increased by a small step, and the voltage on the deflector plates was varied until 100% transmission is restored. The deflector voltage can be applied in the symmetric mode, where equal but opposite voltages are applied to plates of the same pair, or in the asymmetric mode where the voltage is applied only to one plate with the other plate held at ground potential. In figure 2 the beam energy has been converted to the equivalent mass at 3 MeV. Both the symmetric and asymmetric modes gave a linear response over a range of ~3% of relative mass change. A flat top transmission was obtained with the equivalent mass resolution of 1300 and remain so over the same range (figure 3). At greater deflection voltage the flat top deteriorates indicating loss of resolution. The transmission efficiency remains flat over the same range, dropping gradually at higher voltages for the symmetric mode (figure 4). The drop is more rapid for the asymmetric mode indicating the lens effect of the deflector plates. The 3% range corresponds to 6 amu range at mass 200, and to ~3 amu at mass 90, which are sufficient for Pb (mass 204 to 208) and Sr isotopes measurements respectively.

Tests with heavy ion beam yielded similar results. Figure 5 shows the $^{208}Pb^{4+}$ ions detected at the high energy from injected $^{208}PbS^-$ ions, at various settings of the magnet as a function of the deflector voltage, showing the linearity of the response and constancy of the transmission efficiency, over a range corresponding to +/- 3 amu.

While instability can arise from many sources, e.g. accelerator voltage, beam transport elements, one of the main causes is the ion source itself. The advantage of fast bouncing is demonstrated in figure 6, showing the PbS- beam detected at the low energy, as a function of the bouncing speed. The left figures correspond to bouncing cycle of a few seconds whereas the right figures to the order of a second (200 ms per isotope). The intensity of the $^{204}PbS^-$ is close to the noise level of the Faraday cup and most of the fluctuations are just this noise. But for the more intense peaks ($^{206}PbS^-$, $^{207}PbS^-$ and $^{208}PbS^-$) the variation is more gradual with increasing bouncing speed. The ratios absorb some of the fluctuations, but as can be seen, the faster bouncing speed improve the constancy of the ratios even more. Variation of less than 1% can be achieved easily with bouncing cycle of ~1 second.

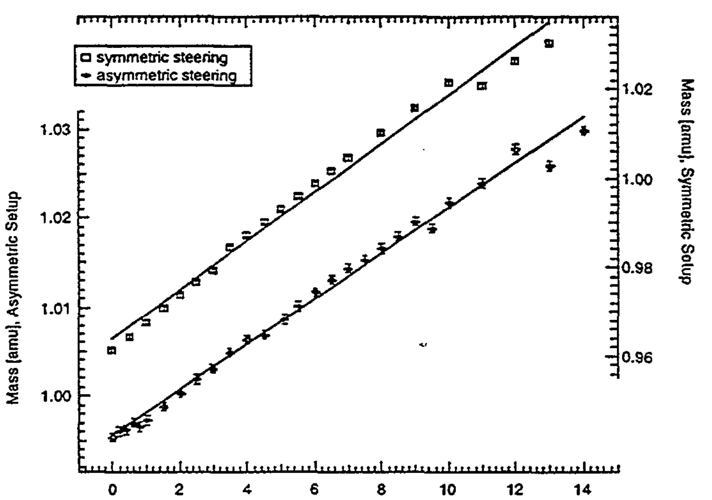

Figure 2. Test of the deflector plates with 3 MeV protons. The proton beam energy variation has been translated into the equivalent mass for a 3 MeV beam. Both the symmetric mode, where the voltages on the pair of plates are equal but opposite, and the anti-symmetric mode, where one of the plates is grounded, give linear response.

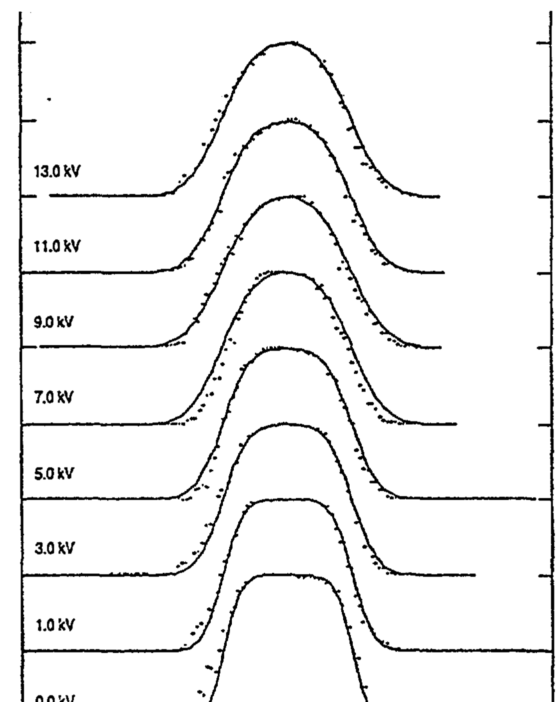

Figure 3. The beam profile remains flat over a significant range of deflection and deteriorates at higher deflection, accompanied by a decrease in transmission.

Conclusion

A fast bouncing system for the high energy end of an AMS system has been devised for the AUSTRALIS system. Based on a method designed for excitation function measurements, the method adapts readily as an isotope sequencer for AMS at the high energy side. Synchronised with the low energy side bouncer, the system will enable isotope ratios measurements with high precision by overcoming drifts in the source, beam transport and the accelerator itself.

References

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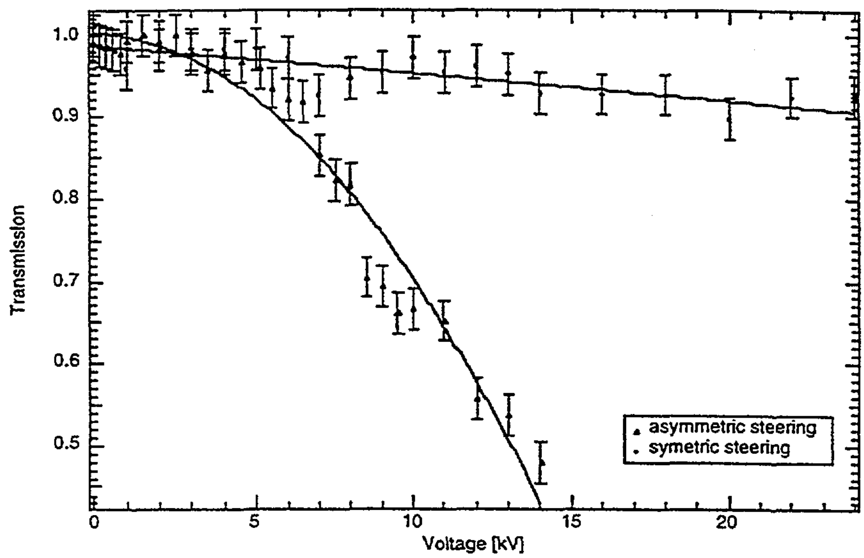

Figure 4. The transmission efficiency for the symmetric mode remains flat for a significant range of deflection voltage. The more rapid drop in the asymmetric mode reflects the lens effect.

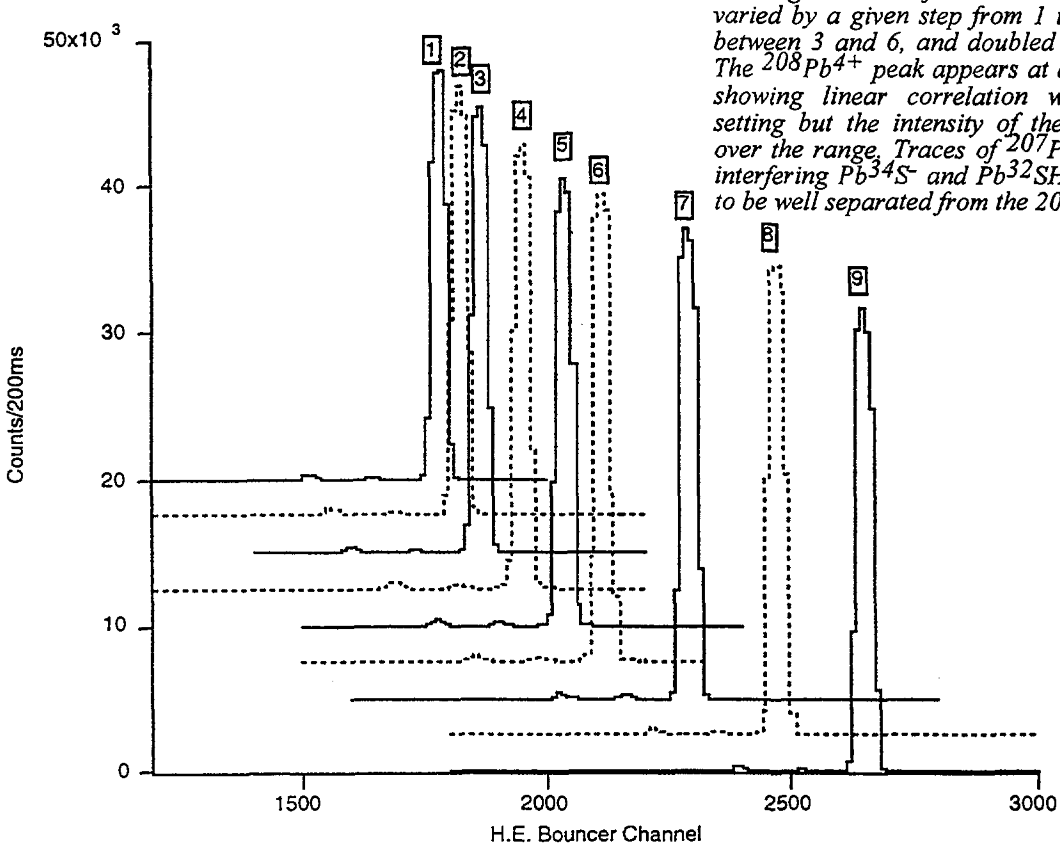

Figure 5. Test of the high energy bouncer using $^{208}Pb^{4+}$ beam from an injected $^{208}Pb^{32}S^{-}$ ions, showing a series of bouncer scan. The magnet field is varied by a given step from 1 to 3; the step is doubled between 3 and 6, and doubled again between 6 and 9. The $^{208}Pb^{4+}$ peak appears at different bouncer setting, showing linear correlation with the magnetic field setting but the intensity of the peak remains constant over the range. Traces of $^{207}Pb^{4+}$ and $^{206}Pb^{4+}$ from interfering $Pb^{34}S^{-}$ and $Pb^{32}SH^{-}$ molecules can be seen to be well separated from the 208 peak.