HEAVY ION STRIPPING BY WRINKLED CARBON FOILS

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A more durable carbon foil for ion beam stripping in tandem accelerators has been sought by many laboratories.¹⁻¹⁰ Since foil stripping yields a higher average charge state than gas stripping, more energetic ions are produced, effectively increasing the useful energy range of the accelerator. As research at tandem accelerators is focused increasingly on heavy ion nuclear physics, the problem of foil lifetimes will become increasingly troublesome. Although the mechanism of foil destruction is not well known, the trend of decreasing foil lifetime with decreasing ion velocity is well established.

The higher energies obtained through foil stripping are gained at the expense of accelerator operating time. At Argonne, we have frequently injected currents of 1 μ a of ^{32}S at a terminal voltage of 8.5 MV. Under these conditions, foil lifetime is only about 1 hour. Our foil changer is a commercially available model* which holds 230 foils; yet this consumption rate implies a new foil loading every ten days. Fortunately for us, accelerator users have not become 100% efficient at utilizing the beam. We can usually leave the beam on the low energy cup for a considerable time — thus conserving foils. Still, tank openings at 20 to 30 day intervals are not unusual and foil replacement is, in general, the primary reason for nearly all our tank openings. In the past, foil replacement required venting of the accelerator tubes and subsequent bakeout and conditioning. This time-consuming process has been greatly simplified in the last year by the installation of terminal

* National Electrostatics Corp., Middleton, Wisconsin.

valves similar to those designed and installed at Canberra.¹¹ Pump out, repressurization, and conditioning can now be accomplished in 36 hours or less. In spite of this improved turnover time, at this foil consumption rate the mere job of mounting the foils is burdensome. Clearly, as the desire for still heavier ions intensifies and foil lifetimes decrease still further, the situation will become intolerable.

Although gas stripping does reduce the average charge state, it is still an attractive option for those experiments which do not require maximum energy. This is especially true for tandem accelerators combined with post-accelerators such as at Argonne. Nevertheless, gas stripping is difficult to accomplish in a vacuum upgraded tandem. Differential terminal pumping, and all its associated complexities, is most likely required. For all these reasons, we found the results which were reported from Daresbury¹² utilizing mechanically slackened or wrinkled foils very encouraging.

The wrinkled foils were attractive because of the straight-forward method of extending the lifetime. Whatever the microscopic mechanism, clearly the immediate cause of foil breakage is the extreme stress developed within the foil. We have produced wrinkled foils by the Daresbury technique. Figure 1 shows the typical appearance of a wrinkled foil before irradiation. The initial aperture area of the foil has been reduced by approximately 6%.

The lifetime of these foils was determined by exposure to a 3 MeV ⁸⁴Kr beam produced by the Argonne Dynamitron accelerator. Figure 2 shows a layout of the experimental apparatus. The beam was collimated by the 4 jaw slits and the 1/16 inch diameter aperture in front of the carbon foil. The stripped ion beam was collected in a faraday cup. The foil condition was monitored by the TV camera and a strip chart record of the current. Normal and wrinkled 5 $\mu\text{g}/\text{cm}^2$ carbon foils were alternately tested. The incident beam current was determined immediately prior to introducing the

the foil. All foils were made from commercially available slides.[†] Each was dipped in a 7% solution of collodion in isoamyl acetate before being floated off in distilled water and mounted. The results are shown in Fig. 3. The normal foils had a relatively well defined lifetime, averaging about 6 minutes to breakage. The wrinkled foils survived for an average of 30 minutes, although one lasted considerably longer than the others.

Offline tests are a useful test of stripper performance, but the final test must be done in the terminal of an accelerator. In most offline tests, current densities are higher and lifetimes shorter than for foils exposed in a terminal. Also, most offline tests reveal only the total beam transmitted while in practice the transmission for a particular charge state is of more interest.

$3 \mu\text{g}/\text{cm}^2$ and $5 \mu\text{g}/\text{cm}^2$ wrinkled foils were loaded into the terminal of the Argonne FN tandem along with $5 \mu\text{g}/\text{cm}^2$ normal foils. The foils were irradiated by 150 na and 500 na of ^{58}Ni as measured at the low energy cup and at a terminal voltage of 8 MV. The results are shown in Fig. 4 where the transmission ratio of $^{58}\text{Ni}^{10+}$ has been plotted against exposure time in na hours. This transmission ratio depends on the characteristics of the accelerator and on the multiple scattering of the incident beam by the foil.

The transmission ratio for the normal foils remains essentially constant until breakage at about 125 na hours. The wrinkled foils, however, have not shown any precipitous fall in transmitted beam, even after 600 na hours. They do show a steady decrease in the transmission ratio, apparently as a result of thickening. The initial transmission ratio for $3 \mu\text{g}/\text{cm}^2$ wrinkled foils is 0.7, which is about equal to the initial transmission ratio of a $5 \mu\text{g}/\text{cm}^2$ normal foil. The initial ratio for a $5 \mu\text{g}/\text{cm}^2$ wrinkled foil is between 0.5 and 0.55.

[†]Arizona Carbon Foil Co., Tucson, Arizona.

The thickening evident in the behavior of the wrinkled foils is presumably due to hydrocarbon cracking even though the accelerator and terminal is a baked, all-metal ceramic structure. The pumping closest to the accelerator is done by ion and cryopumps. Although there is no direct way of measuring the pressure in the terminal, the pressures at the ends of the tubes are typically in the low 10^{-8} torr range. One possible source of the hydrocarbons is beam induced outgassing of defining apertures. Ions and electrons leaving the foil outside of the acceptance angle of the aperture may liberate hydrocarbons from the metallic surfaces. An additional effect contributing to the thickening may be the mass brought into the beam spot from the remainder of the foil. The future addition of a terminal ion pump should help determine the relative contributions of these two effects.

No new stripping medium proposed for use at the Argonne tandem-linac can be accepted on the basis of lifetime alone. Of equal importance is the energy spread introduced into the beam by energy loss straggling. The quality of the experimental data obtained with the tandem-linac depends on the longitudinal emittance, $\Delta E \Delta t$, of the beam. The emittance is plotted in $\Delta E \Delta t$ phase space at the top of Fig. 5. The experimenter's choice between the bottom two plots depends on whether the desire is for good timing or good energy resolution. Depending on the need, the beam as it leaves the tandem will need to be rebunched or debunched as shown in the phase plots of Fig. 6. The energy loss straggling introduced by the stripping foil increases the area of the phase ellipse, irrevocably degrading the beam quality.

The energy straggling of carbon foils was measured using the beam bunching system shown in Fig. 7.¹³ The system consists of a gridded harmonic

prebuncher, chopper, phase detector and associated oscillators and phasing electronics. To measure the system resolution, the last resonator in the linac was used as a rebuncher. The measured time spread was 48 psec. When the 4 m drift length from the rebuncher to the detector is included in the computation, the system time resolution is determined to be 40 psec. The measurements indicate that the energy straggling in arc-evaporated carbon foils varies approximately as $t^{1/2}$ where t is the thickness of the foil. No significant tails of energy distribution anomalies are found which would make the use of wrinkled foils unacceptable, as shown in the spectrum of Fig. 8. On the basis of these measurements, it is expected that a $3 \mu\text{g}/\text{cm}^2$ wrinkled foil would show an energy loss straggling approximately equal to that of a $5 \mu\text{g}/\text{cm}^2$ unwrinkled foil.

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FIGURE CAPTIONS

- Fig. 1 $5 \mu\text{g}/\text{cm}^{-2}$ wrinkled foil before irradiation.
- Fig. 2 Beamline layout for foil lifetime measurement.
- Fig. 3 Results of wrinkled foil lifetime measurements using 3.0 MeV ^{84}Kr .
- Fig. 4 $^{58}\text{Ni}^{10+}$ transmitted through Argonne FN Tandem Accelerator using normal and wrinkled carbon foil strippers.
- Fig. 5 Longitudinal phase space ellipses at Linac exit and downstream from Linac.
- Fig. 6 The effect of rebunching or debunching on longitudinal phase space ellipse after linac exit.
- Fig. 7 Layout of system used for measurement of energy loss straggling.
- Fig. 8 Time spectra of beam using system of Fig. 8 described in text. The 48 psec FWHM peak is the system resolution.

PHG-15,527

PHG-15,525

BEAM QUALITY

$$\Delta E \Delta t = 5 \text{ keV-nsec} \\ = \text{CONSTANT}$$

TIME-OF-FLIGHT
EXPERIMENT

MAGNETIC-SPECTROGRAPH
EXPERIMENT

TANDEM-LINAC SYSTEM