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LIFETIMES OF CARBON STRIPPING FOILS*

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For the planned accelerator systems consisting of a tandem electrostatic accelerator injecting into a linac or a cyclotron, the tandem may be considered to be a multiply-charged heavy-ion source. In such a source, one looks for good emittance, high charge states, high intensity, a stable energy, and small energy spread. The use of the tandem as an injector may place more stringent conditions on its operation than does its use for nuclear spectroscopy with heavy-ion beams.

The behavior of the terminal stripper will be of crucial importance in the operation of a tandem as an ion source. One can use gas as a stripper. From the point of view of emittance and energy straggling, this is a very good choice. However, the most probable charge state with a gas stripper is substantially lower than the one obtained with a foil stripper. In addition, high currents of very heavy ions may present other problems.

The only well-developed alternative to a gas stripper for heavy ions is carbon foils, and these have three interrelated disadvantages: 1) unnecessary thickness, 2) variations in thickness, and 3) short lifetimes. The thinnest foils in practical use have a thickness of about $3 \mu\text{g}/\text{cm}^2$. This is probably thicker than is usually necessary to obtain charge state equilibrium, and thus it increases unnecessarily the multiple scattering and therefore the emittance of the beam. The lifetime of a foil bombarded by large currents of heavy ions is extremely short. If one reduces the beam current the foil lives longer, but it shows a pronounced increase in thickness with time, which increases the emittance. Moreover, since the thickening is non uniform over the area illuminated by the beam, there is also a marked increase in the energy straggling of the beam.

The changes in appearance of a foil bombarded by heavy ions in the energy range of concern in tandem terminals are illustrated in Fig. 1. Initially the foil has its normal fairly-flat appearance. In the earlier stages of use the foil develops the wrinkled appearance shown in Fig. 1A. Subsequently the foil rather suddenly becomes very taut, with an almost mirror-like appearance, and very shortly thereafter it develops a tear, as shown in Fig. 1B. Both of these foils were exposed in the terminal of the Munich MP tandem. If one continues the exposure, the tear in the foil extends and the foil develops a hole, as shown in Fig. 2.

It is obvious that foil lifetime is a rather poorly defined quantity. In assembling the experience of a number of laboratories with carbon foils for the stripping of heavy ion beams, it becomes clear that the definition of lifetime varies extensively, though typically the accelerator operator considers a foil useless if the analyzed beam from the foil had dropped to 30% or 40% of its initial value. Often the results from the various laboratories are only the considered opinions of the operators and rarely the result of

Fig. 1. Foils exposed in the terminal of the Munich MP tandem (courtesy of H. Münzer).

deliberate measurement. The actual beam intensity and the area illuminated by the beam are usually not well known either. Every operator has seen the occasional foil which lasts several times longer than the average. Several laboratories noted that an occasional foil seemed to lose the ability to strip, but, after a rest period, was successfully used again.

In an attempt to produce a somewhat coherent picture of this conglomerate of experience, some assumptions have been made. (1) We assume that, to a reasonable approximation, the lifetime is inversely proportional to the current density; this is based on our experience with 4-MeV Ni^+ beams from the Argonne Dynamitron. (2) We assume that the current should be expressed in particle μA , under the assumption that the number of particles rather than the total charge incident on the foil is the significant quantity. (3) We assume that the lifetime is a function of ion

Fig. 2. Foil exposed to the 4-MV Ni beam of the Argonne Dynamitron.

It appears reasonable to make adjustments in some cases for the reported lifetimes. Often it appears that the currents reported are currents measured at the low-energy cup. The fraction which actually reaches the stripper foil depends strongly on the matching of the emittance of the source and the acceptance of the accelerator; also, the pressure in the accelerator plays an important role in determining losses for the heavier ions. For example, if an injection current of 1.6 μA yields only 0.07 μA of analyzed beam for the most probable charge state, it is likely that not more than half of the current at the low-energy cup actually reached the stripper foil. On the other hand, if the lifetime measurement is made on a foil outside of the accelerator, the beam usually covers a well-defined spot and has a known current, and no corrections are applied.

The results of the experience at many laboratories for unheated foils is shown in Fig. 3. It is to be noted that the data points from the Berkeley Hilac are in excellent agreement with the Oak Ridge measurements on Argon near 1 MeV/nucleon. The experience of the various tandem laboratories for ions heavier than fluorine is really quite similar. The one high point at low energy is a result from Ferguson et al. at Harwell. In that particular case the foil was in the exceptionally good vacuum of 10^{-9} Torr.

If foils are to be routinely useful as strippers for tandems injecting into an energy booster it is necessary to extend the lifetime and also to prevent the foil thickening and other forms of distortion.

Fig. 3. Lifetime of unheated carbon foils as a function of energy/nucleon for heavy ions. The points near 1 MeV/nucleon are from the Berkeley Hilac and an additional argon point from ORNL. The I and Br points near 0.5 MeV/nucleon are results of Macdonald and Andrews at Chalk River. The argon point near 100 keV is from Ferguson.³ The other points are the common experience of a number of laboratories.

Foil thickening seems to have two origins — the cracking of hydrocarbon vapor or of hydrocarbons absorbed in the foil in the manufacturing process on the one hand and beam-associated effects on the other.

Measurements by a beam-foil spectroscopy group at Liege¹ and Dobberstein and Henke² indicate that the foil-thickening process is entirely due to hydrocarbon cracking when the ion energy is very low. The carbon is deposited uniformly over the area illuminated by the beam and carbon build up is eliminated totally by the use of cold surfaces near the target. The lifetime of the foil does not depend on current density but uniquely on the total number of particles passing through the foil. Heating of the foil increases the lifetime by only 40%. These experiments were done with heavy ions of less than 1 MeV energy and slow N^+ and N_2^+ ions. It is to be noted that the rate of carbon build up was greater for N^+ than for N_2^+ .

By contrast, Ferguson³ obtained quite different results when he used much more energetic argon beams (4.8 MeV) in a 10^{-9} Torr vacuum. He obtained a lifetime of 50 min for a non heated foil. When the foil was heated to 600°C, the average lifetime increased from 50 min to 160 min; and 1000°C the

lifetime was 120 min. The foil failure was entirely due to radiation-induced effects. The beam spot covered an area of 20 mm^2 and the average beam intensity was about $0.5 \text{ } \mu\text{A}$. Scanning the beam increased the lifetime by about a factor of 2 when the ratio of scanned area to the stationary beam spot was 4 : 1. The Harwell experiment indicates that the foil lifetime is sensitive to radiation-induced foil thickening, sensitive to current density, and sensitive to temperature, all of which were absent in the very low energy heavy ion data.

In Ferguson's experiment, the increase in lifetime due to beam scanning is smaller than one might have hoped for if the lifetime were inversely proportional to beam density, and it is also somewhat smaller than the increase observed at Argonne with an oscillating heated foil for a 4-MeV Ni beam,⁴ but one should not be too dogmatic about it. On the other hand, the increase in lifetime obtained by heating the foil is substantially smaller than the one observed in the Argonne work with 4-MeV Ni ions, and this is a much more serious discrepancy. Possibly the explanation is that the Harwell experiment used electron bombardment and fairly high temperatures and the Argonne experiment used radiative heating at lower temperatures. Our electron beam-heating experiments were not very successful and we did not pursue them. Also, our experiments indicate that temperatures of the order of 400°C to 500°C give the best results, and similar results have been obtained by Kay at Canterbury. Our best results with the 4-MeV Ni beam was obtained by simultaneously heating and oscillating the carbon foil. The resulting lifetimes are indicated by the dot in the upper left-hand corner of Fig. 3.

It is known that, if an amorphous carbon foil is annealed at high temperatures, irreversible structural changes occur and physical characteristics such as the electrical conductivity change. However, the lifetimes of foils annealed before use do not differ from the lifetimes of non-annealed foils, and heating during bombardment appears to be necessary. Since there is a high density of current flowing through the foil, one should not have exposed insulators in the vicinity; electrostatic forces are very destructive to thin carbon foils. At one point in our investigations, a thin layer of gold was evaporated on the carbon foil. This improved the foil lifetime by about 50%. Alexander and Macdonald⁴ at Chalk River have used a thin layer of Al on carbon foils and they observed a significant decrease in lifetime.

In our work, the introduction of slow motion of the heated foil was intended less to increase the lifetime than to counteract the thickening effect due to radiation. Such thickening has two aspects - (a) it increases the multiple scattering and (b) it increases the energy straggling. The energy straggling in the foil may be quite important for an application in which short pulses are required. In a beam-bunching experiment, Rudolph⁵ at Munich has measured the pulse width of heavy ion beams. For a $^{32}\text{S}^{7+}$ beam with 9.4 MV on the terminal, the pulse width (FWHM) was 1.43 nsec for a gas stripper and was 1.93 nsec for a carbon foil nominally $5 \text{ } \mu\text{g}/\text{cm}^2$ thick. If one assumes that there is no energy straggling with the gas stripper, the resulting energy straggling from

the carbon foil is 35 keV. Damaged stripper foils result in double peaks in this experiment, since part of the beam passed only through the gas and part through both gas and foils. In Rudolph's experiment these peaks were more than 3 nsec apart. This gives a good indication of the sensitivity of the bunched beam to energy loss straggling and a possible experimental approach to its measurements.

Recently Efken, Hahn, Hilscher and Wüstefeld⁶ have used magnetic analysis to measure energy-loss straggling in thin carbon foils. The inhomogeneity of the foil thickness introduces large uncertainties in these measurements with argon beams at 5, 10 and 15 MeV. The important feature is the change in energy-loss straggling. With beam intensities of $30\text{--}100 \text{ pna}/\text{mm}^2$ at 10 MeV, the energy-loss straggling increased in 20 to 180 min by as much as a factor of 5 while the average energy loss increased only 50%. This result implies that the target thickening effect is quite non uniform.

It is desirable to attempt to control both the thickening effect and its non-uniform character if foil strippers are to be used in a beam-bunching application prior to injection into an energy booster. There is no clear indication at the present time of the nature of the thickening effect. It can either be a result of crystallization in the foil or an atom migration effect. In the low-energy experiments, crystallization of the carbon atoms in the foil was observed. However the thickening effect was rather homogeneous. The difference between very low and tandem-terminal energies appears to be basically the stripping of electrons. From the results of Datz et al.,⁷ it follows that high-velocity ions in solids have lower charge states than those in the emergent beams. The additional electrons leave the surface substantially in the same direction as the stripped ion. The electrons stripped from the heavy ion in the solid are a current source and the current through the foil will give a substantial field gradient. Polarization of the carbon atoms may tend to promote migration of the atoms towards the edge of the beam spot. There is some indication that the ridge building takes place rather close to the inside periphery of the beam spot and a corresponding decrease in thickness occurs just outside the periphery. Therefore it seemed likely that a fairly slow motion of the target might be helpful. In our experiments this appeared to be true.

The inhomogeneity of the carbon foils is, of course, a disturbing feature, since the beam spot at the terminal usually has a diameter in excess of 3 mm. Mair-Komor has recently investigated the effect of the detergent used in the production of carbon foils and has shown that the foil uniformity is very dependent on the choice of parting agent. It seems possible that a careful investigation of the manufacturing process may also yield foils with a substantially improved lifetime.

A tandem can be operated with a gas stripper in the terminal and a foil stripper in a dead section in the high-energy end of the accelerator. Experiments at Brookhaven⁸ have shown that the lifetime of a foil used with a Ni beam in a dead section in the MP tandem was about a factor 10 longer than a foil

used in the terminal.

In our opinion the use of foil heating in the tandem terminal during heavy ion bombardment combined with oscillation of the foil will produce acceptable foil lifetimes and improve the beam quality by reduction of the foil thickening effect and the accompanying inhomogeneity. The installation and operation of such a system does not present insurmountable problems. The construction of our test assembly for the terminal of Argonne FN tandem is nearly completed and will be installed in the near future.

I am indebted to many laboratories for their willingness to share their operating experience. The work at the Argonne Dynamitron and the development of the test arrangement at the FN tandem has been done in collaboration with John Bicek.

References

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¹P. D. Dumont, A. E. Livingston, Y. Bandinet-Robinet, G. Weber and L. Quaglia, to be published.

²P. Dobberstein and L. Henke, Nucl. Instrum. Methods, 119, 611 (1974).

³A. T. Ferguson, private communication.

⁴T. K. Alexander, private communication.

⁵Private communication from H. Münzer.

⁶B. Efken, D. Hahn, D. Hilscher and G. Wüstefeld, to be published.

⁷S. Datz, et al., Phys. Rev. Letters 33, 733 (1974).

⁸P. Thieberger, H. E. Wegner, M. McKeown, M. Manni and I. Feigenbaum, Nucl. Instrum. Methods 122, 291 (1974).