A HIGH DUTY FOIL STRIPPER SYSTEM IN THE INJECTION LINE TO THE HEAVY ION SYNCHROTRON SIS AT GSI

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1. INTRODUCTION

The heavy ion synchrotron SIS in the GSI accelerator facility is designed to accelerate ion beams up to a magnetic rigidity of 18 Tm. The actually achievable final energy is determined by the charge-to-mass ratio q/A of the accelerated beam. A foil stripper in the injection line to the SIS is routinely used to increase the charge states by factors of 1.5 to 3.5 for ions from Ne to U, inferring intensity losses of up to 85% due to the charge state distributions. Stripped uranium ions (73+) can be accelerated to 1 GeV/u.

A new high current injector [1] - replacing the Wideroe-section of the Unilac - is presently under construction. It will deliver beam intensities up to the space charge limits in the SIS for all ions. In order to cope with the potentially disastrous beam load on the stripper foil a magnetic beam sweeping system has been designed that will save the foil and limit the beam quality deteriorations caused by the stripping process as well.

2. INTERACTION OF BEAM AND STRIPPER

The new stripper will be located in the transfer line between Unilac and SIS where the following parameters apply for high current beams:

Ion:	any species
Energy:	11.4 MeV/u
Velocity:	0.155 c
Intensity:	$\leq 3{\cdot}10^{11}$ part. per pulse
Pulse duration:	100 us
Pulse repetition:	$\leq$ 5 Hz
Emittances:	$\varepsilon_x = \varepsilon_y = 1\pi$ µm (normalized)
	$\varepsilon_z = 0.2{\cdot}\pi$ ns %

As the requirements for the stripper are more stringent for heavier ions the following discussion will concentrate on uranium ions.

U^{28+} ions from the Unilac are stripped in a carbon foil to an equilibrium charge state distribution if the foil thickness exceeds approximately 500µg/cm² . The distribution is about 10 charge states wide and peaked at 73+ with an intensity fraction of 13% (Fig.1). By charge analysis only this fraction will be selected for injection into the SIS.

In the stripping process the statistical collisions between the ions and the atoms in the stripper lead to energy loss and angular scattering with Gaussian distributions and to heat transfer into the foil.

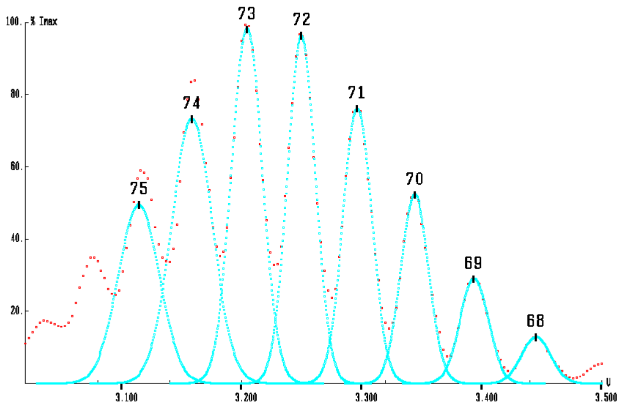

Figure 1: Charge state distribution of uranium beam stripped in a 0.5mg/cm² carbon foil at 11.4MeV/u

Resulting parameters are:

Mean energy loss:	230 keV/u (2%)
Energy loss variation from 10% foil non-uniformity:	23 keV/u
Energy straggling:	5.6 keV/u (FWHM)
Angular straggling:	1.0 mrad (FWHM)
Energy deposited in foil:	2.6 Ws per pulse
Heat capacity of foil up to sublimation point:	1.0 Ws/cm²
Sublimation temperature at 10^{-6} hPa:	2000 K

The parameters reveal undesirable effects to the foil as well as to the beam:

- with beam spot areas $\leq$ 2.5 cm² the foil will be evaporated during a single beam pulse
- energy and angular stragglings will induce emittance growth in all three phase planes in proportion to the respective beam widths

Tolerable emittance growth factors with respect to injection into the SIS are 1.1 and 2 in the horizontal and vertical phase planes, respectively, implying an upright beam spot of 4 mm width and 20 mm height. This would be far too small to avoid evaporation. One method to achieve a horizontal beam widening without affecting the emittance growth is to ‘sweep’ the beam spot over the 50mm wide stripper foil during a single beam pulse (Fig.2). The thereby irradiated area of 10 cm² is loaded with tolerable 0.26 Ws/cm². In 5 Hz-operation The foil will be heated up to 1100 K in every beam pulse and cool down to 500 K before the next pulse. At a more likely pulse repetition rate of 0.5 Hz the foil temperatur will vary between 900 K and room temperatur.

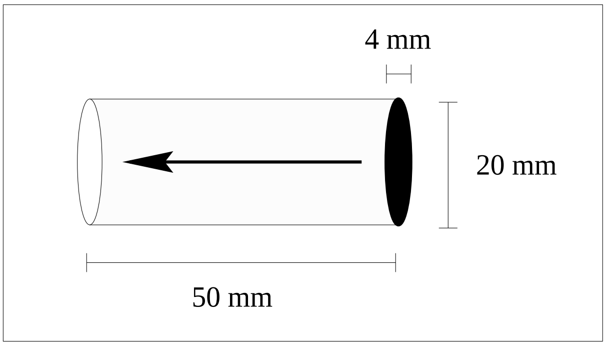

Figure 2. Scheme of beam motion over stripper foil. The effective beam spot area is enlarged by a factor of 16

3. BEAM SWEEPER SYSTEM

In Fig.3 some suitable beam-sweeper configurations are shown which have in common the use of two fast bending magnets ('sweepers') for the deflection of the beam away from and back onto the beam line axis. The larger return bend may be accomplished by another sweeper magnet, or by a quadrupole lens or a wedge-shaped dipole magnet with fixed field. (It is intended to use a dipole magnet and to exploit its charge analysing capability as well; see below).

During the beam pulse the two (or three) sweeper magnets are ramped down to near zero from their individual starting fields which depend on the beam charge states before and after the stripper. Exact synchronism of the field ramps is required in order to prevent artificial emittance growth arising from transient misalignment of the downstream beam.

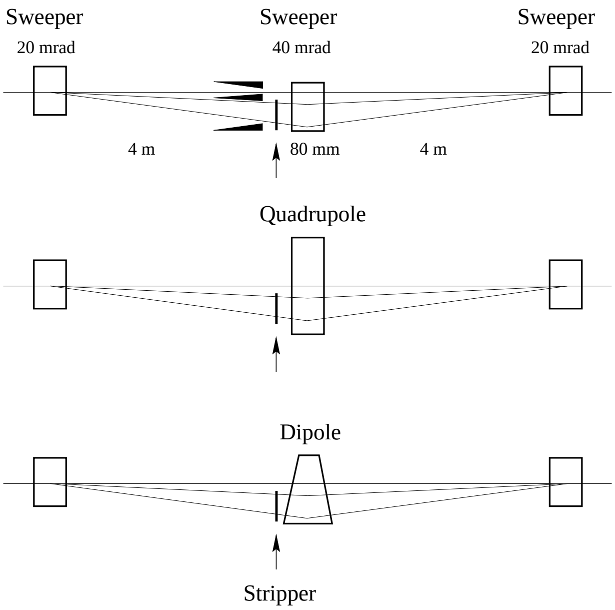

Figure 3. Methods of beam sweeping with fast ramped magnets. The center bending element may be a focusing fixed-field magnet.

* Trademark of Vakuumschmelze GmbH,Hanau

The design of the sweeper magnets will be similar to the 'bumper' magnets in the SIS. The technical data are given in Table.1.

Sweeper magnet power supplies are presently being designed on the basis of power transistors (1200A/1200V; Eupec 16BTFZ 1200R12) taking into account cable and magnet inductances.

Table 1. Technical data of sweeper magnets

Maximum field	0.2 T
Effective length	0.5 m
Gap height x width	71 mm x 105 mm
Field ramp	2000 T/s
Tracking tolerance	0.2 mT
Number of coil turns	4
Resistance	460 µOhm
Inductance	16 µH
Maximum current	2800 A
Ramp voltage	460 V
Yoke material	Corovac*
Magnetic susceptibility	600
Chamber material	ceramics
Chamber aperture	45 x 71 mm²

4. BEAM DYNAMICS

For the projected high current beams the charge multiplication by stripping may cause space charge problems in the beam transport to the charge separator. Calculations with the particle code PARMTRA have shown that e.g. for the stripped uranium beam (35emA; average charge state 73) transverse emittance growth by a factor of 2 must be expected in a 20 m long transport line, whereas factors of <1.2 may be tolerable. After charge state separation the intensity - and so the space charge forces - are reduced by one order of magnitude to an uncritical level.

Already at beginning separation in a magnetic field the emittance growth of the partial beam of interest - in the center of the distribution - will be strongly damped not only due to the increasing beam diameter but also by the deflection of neighbouring charge states which tends to flatten the space charge potential seen by the central partial beam.

In order to obtain the charge separation as close as possible to the stripper it is favourable to use a high separator magnetic field and to analyse in the plane of the smaller beam diameter. Consequently, analysing and sweeping are both to be performed horizontally. using the same magnet. The optics, shown in Fig. 4 in thin-lens approximation, should ideally provide a point-to-point transformation between both sweepers and, simultaneously, between the stripper and the analysing slits (requiring half a betatron wavelength over both distances), and at the slits the dispersion for one charge state should exceed the beam width.

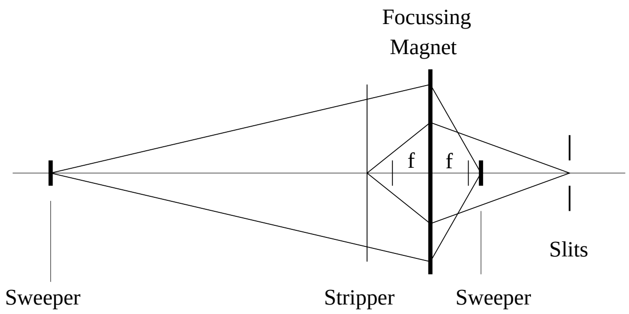

Figure 4: Simple optics equivalent of the combined function of beam sweeping and focussing for charge analysis. The focal length of the bending magnet is f.

However the stripper need not necessarily be located outside one focal length as prescribed by the optics; due to the limited beam divergence the charge separation may also be obtained using a shorter distance. Various magnet geometries were tested at a field of 1.6 T and satisfactory solutions were found for stripper-to-magnet distances down to 0.4 m and for bending angles greater >15°.

A straight-sighted stripper section, suitable for installation in the transfer line, has been drafted using four 30°-dipole magnets in a deviation arrangement. Fig. 5 and Fig.6 show that backbending of the sweeping beam and charge analysis can both be achieved with only the first magnet (pole face angles of 40° and 0°), the others restore the beam axis and the dispersion. The stripper-to-magnet distance, now 1.3 m, could be reduced wihout sacrificing the charge separation in the center of the system.

The beam deflection is unipolar and covers 70 mm in the stripper plane, allowing a straight beam to pass outside the stripper foil for unstripped operation. The second sweeper follows only 0.5 m after the magnet.

From particle-particle calculations for this system the emittance growth by space charge forces was estimated to be <20% transversely and <5% longitudinally, satisfying the requirements. However, in the further course of optimisation, space charge effects arising in the process of charge state separation must be considered in detail. An appropriate particle code is not yet available.

5. CONCLUSION

A stripper section has been designed that seems well suited for the anticipated high current beams at GSI. The various imposed requirements as tolerable stripper foil heating, tolerable emittance growth in the foil and by space charge forces, charge analysis, dispersion-free and straigh-sighted beam transport could be met without severe compromises.

6. REFERENCE

[1] Beam Intensity Upgrade of the GSI Accelerator Facility, GSI-95-5 Report,1995

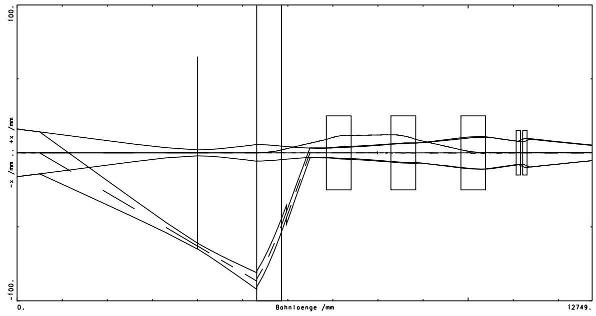

Figure. 5: Horizontal beam envelopes at zero and maximum deflection, covering 70mm in the stripper plane. ‘Sweeping’ within a beam pulse length of 100µs is done by two small fast ramped magnets and a focusing dipole magnet. Beams coincide in the charge analyser section.

Scales: horiz. 12.75 m, vert. ±100 mm

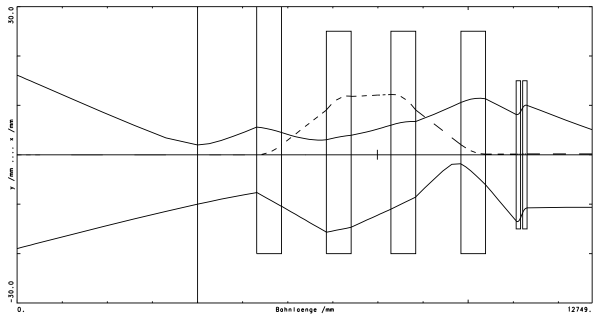

Figure 6: Horizontal and vertical envelopes of straight beam. and dispersion for 1/73 charge state difference (dotted line). Charge state selection after the second of four 30°-dipole magnets.

Scales: horiz. 12.75 m, vert. ±30 mm