THE CHARACTERISTICS OF THE CYCLOTRON JULIC AS INJECTOR FOR COSY

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ABSTRACT

The way of filling the cooler synchrotron COSY–Jülich reliably by stripping injection dependant on the characteristics of the cyclotron JULIC as injector is described.

INTRODUCTION

COSY–Jülich is designed as a rapid cycling synchrotron with electron and stochastic cooling devices to diminish the phase space. The momentum ranges between 300 MeV/c and 3.3 GeV/c. The magnets are arranged in a racetrack. The two straights have a length of 40 m each. The arcs have a 6 fold symmetry. The maximum tunes are of the order of 5, the betatron amplitudes range between 1 and 50 m. The dispersion in the ring is lower than 25 m. The acceptances are 150 π mm mrad in the horizontal and 35 π mm mrad in the vertical plane.

It is the goal of the COSY–Jülich project[1] which has been started in 1987, to provide beams with intensities up to 10^{11} particles (protons) and emittances as low as 0.5 π mm mrad in the ring. The cyclotron JULIC[2] since more than two years equipped with ECR–sources and an axial injection system[3] will be the injector. First COSY–beam is expected by the end of 1993.

BEAM QUALITY AND ION SPECIES

From previously[2] and recently[3] measured data the cyclotron beam quality for the design of the stripping injection is described by the following values of emittances, momentum and phase width, respectively

$$\epsilon_h/\epsilon_v = 3.2/6.4\ \pi \text{ mm mrad (90\% intensity)}$$
$$\Delta p/p \text{ FWHM}) = 1.5/1000$$
$$\Delta\phi \text{ (FWHM)} = 14^\circ \text{ RF}$$

The stripping injection of positive ions is feasable for stripping ratios $|\kappa| \geq 4/3$. Provisions for the stripping injection of negative ions, i.e. H^- and D^-, have been designed as well. Table 1 lists the light ion candidates for stripping injection. Up to now 11 eμA of H_2^+–molecular ions have been extracted from the cyclotron. This corresponds to 2.5 10^8 protons in the ring per turn. Negative ions available with currents in the enA–region for test purposes have been successfully accelerated. In despite of the polarity reversal at the septum deflector H^- ions have been extracted at the upper limit of 45 MeV/A and D^- ions at the lower limit of 22.5 MeV/A of the energy range of JULIC.

Table 1: Light ions for the stripping injection into COSY

Particle	Charge to Mass Ratio	Energy (MeV)	Ratio $\kappa=(Q/A)^*/(Q/A)$	Circulating Particles
H_2^+	0.500	80.0	2.0	p
HD^+	0.333	67.5	1.5	d
$^3H^+$	0.333	67.5	1.5	τ
H^-	–1.0	40	–1.0	p
D^-	–0.5	80	–1.0	d

*after stripping

Table 2 lists the medium mass ion candidates. For medium mass ions typically 1/10 of the source currents is available at the cyclotron exit. $|Q/A| \geq 1/3$ is a necessary presupposition for the operation of the cyclotron. Unfortunately power limitations due to an insufficient

Table 2: Medium mass ions for the stripping injection into COSY

Particle	Charge to Mass Ratio Q/A	Ion source Current (eμA)	Energy (MeV)	Ratio $\kappa=(Q/A)^*/(Q/A)$
$^{12}C^{4+}$	0.333	55	270	1.50
$^{14}N^{5+}$	0.357	100	315	1.40
$^{16}O^{6+}$	0.375	90	360	1.33
$^{20}Ne^{7+}$	0.350	40	450	1.43
$^{32}S^{11+}$	0.344	10	720	1.46
$^{40}Ca^{14+}$	0.350	–	900	1.43

*after stripping

current carrying capacity of frequency tuning elements in the accelerating system do not allow a proper operation of the RF–system near this border.

As can be seen from both tables the energy per nucleon to be injected is either 40 or 22.5 MeV/A corresponding to cyclotron RF frequencies of 28.0 and 21.3 MHz, respectively. The ring circumference accomodates exactly 60 cyclotron bunches. Thus the lowest frequency needed for the h = 1 accelerating cavity of COSY is 355 kHz.

IMPROVEMENT OF CYCLOTRON COMPONENTS

Two important improvements are now under way at the cyclotron because of reliability reasons[4].

The present trim coils make use of epoxy resin for the insulation. The radiation damage due to 15 years of operation has reduced insulation and cooling severely. Mineral insulated square shaped Cu–conductors covered by sheath copper in conjunction with rectangular water-cooling tubes now allow a perfect solderability into the backing copper plates (see figure 1). Radiation damage

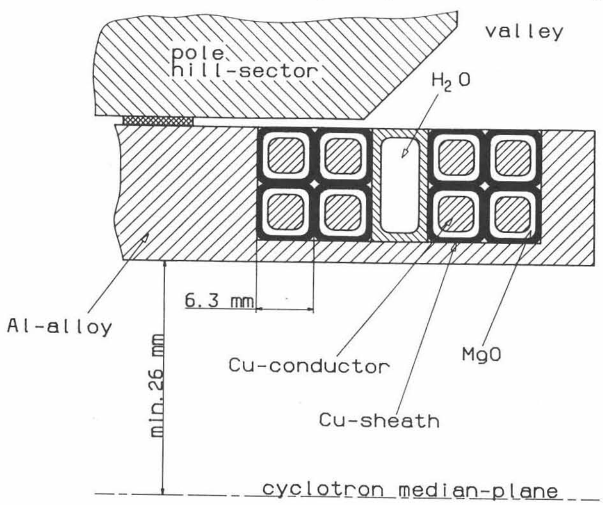

Figure 1: Part of a typical cross section of a trim coil plate near the cyclotron centre.

and outgasing problems will be thus mimimized. Stripping losses during the 3 km travel of H_2^+–, H^- and D^-–beams in the cyclotron will be reduced as well. The design of the trim coil system has been reviewed and optimized. It was possible to reduce the number of coils per plate from 12 to 9.

A new driven RF–system will replace the more than 20 years old self oscillating unit. The old power generator using antiquated triodes will be removed from the top of the vertical feeder line and replaced by a power amplifier with a standard output impedance of 50 Ω feeding the resonator system by inductive coupling of one of the three accelerating sectors (see figure 2). The coarse frequency tuning system via panels will be equipped with a new precise motion control. This makes it possible to remove 4 rotating watercooled loops in each sector used at present for frequency fine tuning. Frequency fine tuning will be accomplished in the future by elements mounted at the end of the vertical line. The achievable better frequency and amplitude stability of several parts

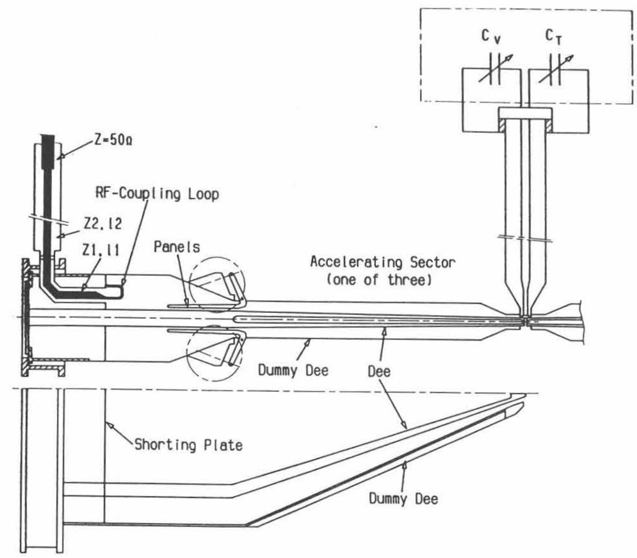

Figure 2: Modified RF–system; cross–section through one dee, coupling loop inclusive impedance matching with coaxial lines, vertical resonator line, panels for coarse frequency control.

in 10^{-6} and 10^{-4}, respectively, will result in a much more stable cyclotron beam quality. Phase stability of the cyclotron bunches specified to be within 1° RF will facilitate a future longitudinal stacking injection into the ring.

CYCLOTRON BEAM ACHROMATIZATION

Instead of taking the emittance at the exit of the cyclotron as inherited despite of intrinsic dispersion correlations the beam transfer between the entrance of the septum deflector and the cyclotron exit is combined with the first section of the beam transfer line for beam achromatization purposes. If we anticipate for JULIC an incoherent amplitude $A_i = 2$ mm a rectangular emittance with normalized angle coordinate $\Theta = (R/Q_R) \cdot \Theta$ (R extraction radius, Q_R radial betatron frequency) is given by $\epsilon_x = (2A_i)^2 = 16$ mm². Figure 3 displays how this phase space is being cut into pieces at the septum during multiturn extraction. Due to the overlaying combination almost no dispersion correlation is encountered at the septum entrance. Because of the dispersion, which the beam has catched during the passage to the cyclotron exit, the phase space figure broadens by a factor of almost 3 and recombines at the end of the first part of the beam transfer system, which is set for beam achromatization. Therefore an improvement factor of almost 3 for the horizontal cyclotron emittance is in principle to be expected in comparison to the present situation.

BEAM TRANSFER BETWEEN JULIC AND COSY

Besides beam achromatization the first section I1 of the beam transfer system (see figure 4) supplies at the same time the match for two sets of twiss parameters of the COSY ring, i.e. $\beta_x = 15$ m, $\beta_y = 7$ m and $\beta_x = 7$ m, $\beta_y = 15$ m, all other being 0 in both cases.

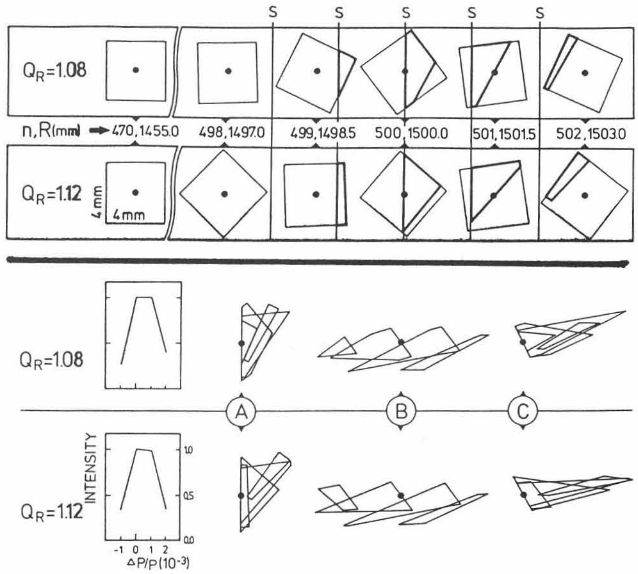

Figure 3:
Above: Radial phase space figures during multiturn extraction using normalized coordinates in mm; n–turn number, R cyclotron radius, S–septum.
Below: Momentum distribution and radial phase space areas of the extracted beam after the septum (A) at the cyclotron exit (B) and after beam achromatization (C).

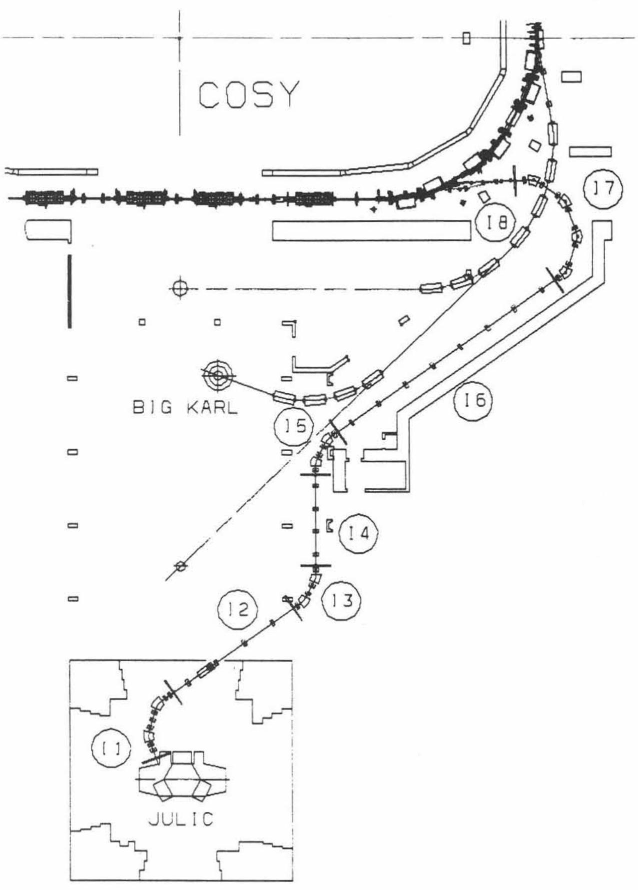

Figure 4: Layout of the beam transferline between JULIC and COSY. I1 through I8 beam line sections.

Section I_2 is a FODO telescope with $M^2 = -I$ behaviour. M represents an optical module with phase advance $\pi/2$ and I is the unit matrix. The sections I3 and I5 contain 4 cells, which are identical, except that each two dipole magnets are bending in opposite directions. Therefore section I4, a FODO telescope with $M^2 = -I$ inbetween is needed to make up an achromat, which has the same features as the $M^4 = I$ achromat of section I7 except for a $-I$ overall transfer matrix. Section I6 is a pair of FODO telescopes again with $M^4 = I$ symmetry. Section I8 is a telescope with identical magnifications $M_x = M_y = -1.5$. This is valid for the injection lines suited for negative as well as for positive ions which are shown splitting to the left and right seen with the beam direction, respectively, in the second part of section I8.

The telescopic property of the modules produces imaging with simultaneous waist to waist transformation. This leads to a simple beam diagnosis system, where the operator subsequently checks the equality of beam profiles at the exit of the modules of the system. The use of $M^4 = I$ symmetry automatically results in the cancellation of all second order geometric aberrations for more than 60 m of the 100 m long travel (sections I3 through I7).

FILLING COSY

The coasting beam space charge limit dependinging on the emittance in the ring has been calculated from the formulars given by C. Bovet et. al[5] for the simplified case of a round beam ($\epsilon_x = \epsilon_y$, $Q_x = Q_y$). The allowed tune shift has been taken as $\Delta Q = 0.02$.

The curve describing the filling of COSY by the stripping injection of a H_2^+ –80 MeV cyclotron beam is given by the cyclotron beam current, the time needed for one revolution in the ring and the emittance growth due to foil passages taken as $\epsilon_n = \epsilon_0 + 2\, n\, ß\, \Theta^2_{rms}$ with n being the number of foil passages, ß the Twiss parameter, Θ_{rms} the root mean square of the multiple scattering angle at the stripping foil and ϵ_n the 2σ–emittance[6].

Detailed measurements of the stripping cross section have been carried out at JULIC[7]. Figure 5 shows as one result the proton production rate versus the target thickness for a 80 MeV H_2^+–beam. 20 $\mu g/cm^2$ C and 13

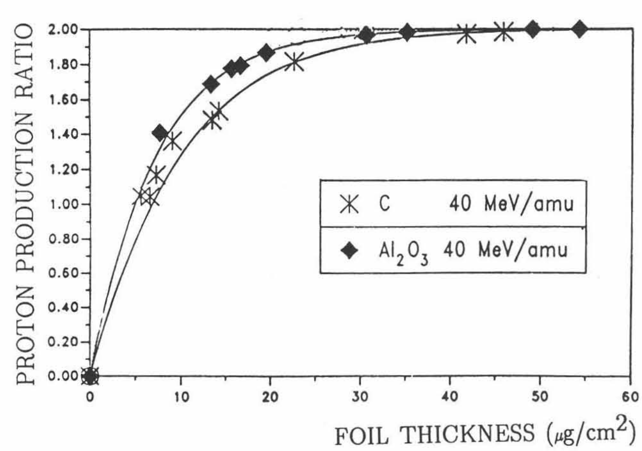

Figure 5: Proton production versus target thickness for a 40 MeV/A H_2^+–beam

$\mu g/cm^2$ Al_2O_3 foils have about the same stripping efficiency of more than 80%. By chance these foils produce about the same emittance growth, i.e. $\Theta_{rms} = 0.04$ mrad.

Figure 5 displays the coasting beam space charge limit and the filling curves for two cases. The filling curve devides the diagram into two regions where electron cooling is most (left) and less benifitial.

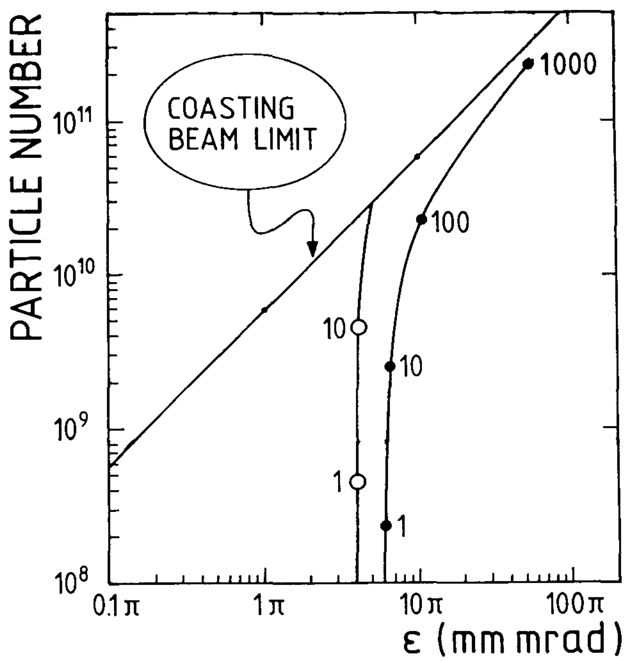

Figure 6: Coasting beam space charge limit and filling curves

- • 10 eμA H_2^+, 100% passage through stripping foil, $\epsilon = 6\ \pi$ mm mrad
- ∘ 20 eμA H_2^+, 25% passage through foil stripping foil, $\epsilon = 4\ \pi$ mm mrad.

The bunched beam space charge limit is roughly a factor of 3 smaller than the coasting beam limit. Because of the given dispersion in the ring and the given momentum spread of the cyclotron beam longitudinal phase space manipulations are necessary to reach this limit. Macroscopic beam pulsing and/or prebunching prior to injection are under consideration.

CONCLUSION

Care has been taken to investigate and design the necessary hardware for a successfull and reliable stripping injection into COSY. More detailed investigations and calculations are necessary to understand the best way of filling COSY. Especially the number of foil passages has to be minimized taking into account the beam matching, the thickness and the form of the stripping foil and the use of quick bumper magnets.

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