BEAMLINES FOR A SECOND INJECTOR CYCLOTRON AT NAC

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ABSTRACT

A second solid-pole injector cyclotron (SPC2) is at present being constructed to provide pre-accelerated heavy ion beams and polarized hydrogen ions for acceleration into the K=200 MeV sector cyclotron (SC) at NAC. The transfer beamlines from an ECR source to SPC2, and from a polarized ion source to SPC2 are described, as is the transfer beamline from SPC2 to the SC.

1. INTRODUCTION

The large sector cyclotron (SC) at NAC[1] is designed to accelerate protons to some 200 MeV, and also to accelerate a variety of light and heavy ions. It has operated successfully for several years now, with the solid-pole injector cyclotron SPC1 providing the necessary pre-acceleration of light-ion beams from its internal hooded-arc PIG ion source. A second injector cyclotron SPC2, very similar in size to SPC1, is now under construction[2] and will provide pre-accelerated heavy-ion and polarized-ion beams, produced in two external ion sources. The two injector cyclotrons are situated at ground level (datum level zero), with their horizontal median planes level with that of the SC, *i.e.* at +1.5 m height. The SC vault extends downwards to the basement, 4 metres below ground datum.

As can be seen from Fig. 1, these new ion sources are situated in the basement below the second injector SPC2, and on opposite sides of it. Both sources are arranged horizontally, with their beams produced at 1 metre above floor height, *i.e.* at 3 m below ground datum. Beam transport systems are therefore required to guide particle beams from both the ECR ion source and the atomic-beam polarized ion source, up into the common vertical axial injection beamline of SPC2.

On leaving SPC2, the pre-accelerated particle beams have then to be transported towards the SC, which means that the beamline must join that from SPC1, after which the injection path into the SC is the same.

2. THE ECR TRANFER LINE

The beamline from the ECR ion source has been described previously[3] in some detail. We briefly summarize the design here for the sake of completion. This line is shown on the left of Fig. 2, part in plan and part in section, because the line is a "twisted achromat" with one 90° dipole B1Q operating in the horizontal plane, followed by a second (identical) dipole B2Q bending the beam into the vertical direction. A single (movable) solenoid lens L1Q controls the divergence and focuses the initial beam from the horizontal ECR source onto the objective slit aperture, where some initial (partial) rejection of unwanted charge-states takes place.

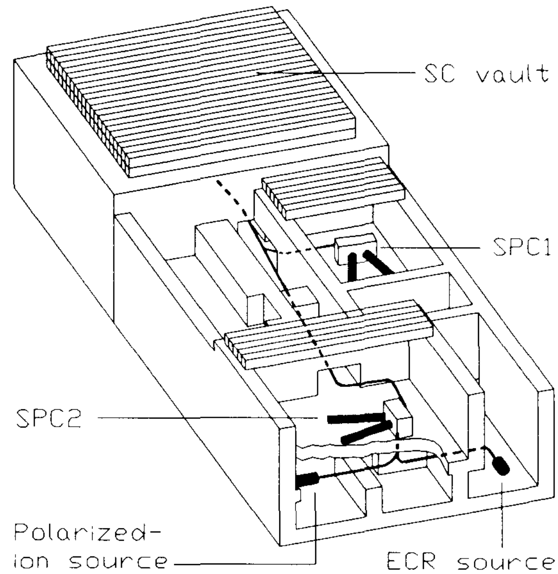

Fig. 1. Layout of the transfer beamlines at NAC.

After the first 90° analysing magnet (Fig. 3) has completed the charge-state selection, the plane of dispersion is horizontal, and two pairs of solenoid lenses L2Q-L5Q then transport the selected particle beam along to the second dipole magnet. The first two lenses (L2Q and L3Q) are operated with opposing polarities, and therefore impart no net rotation to the dispersion plane. The next two lenses (L4Q and L5Q) are operated in the same sense, and impart approximately 90° of rotation, so that the plane of dispersion is vertical.

A solenoid "field lens", formed by two solenoids R1 and R2 with opposing fields so as to impart no net rotation, is placed at the symmetry point of this system

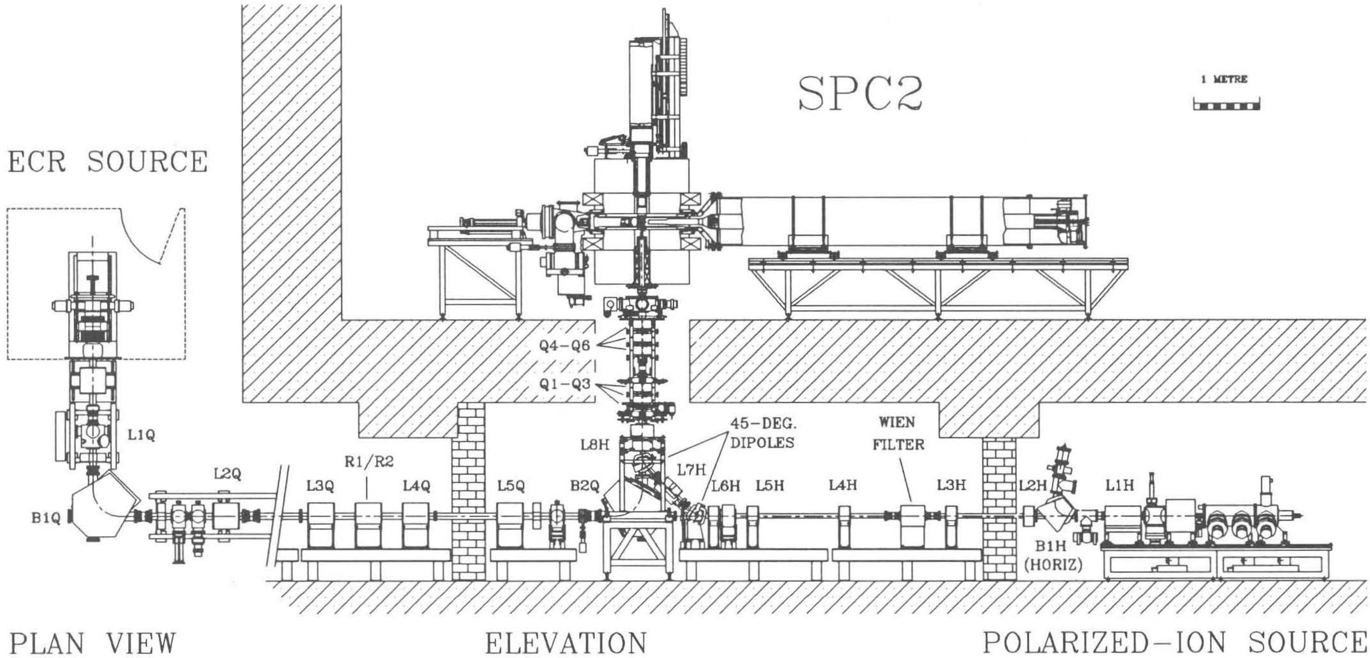

Fig. 2. The transfer beamlines between the ECR and polarized-ion sources and the injector cyclotron SPC2.

and allows us to focus the dispersed particles correctly, so that the entire system is achromatic. The midpoint of the system is also a horizontal and vertical waist, so that the focusing of the system as a whole is not affected by the operation of the field lens. As the focusing of the solenoid lenses may need fine-tuning, which would also affect the rotation of the plane of dispersion, we have manufactured the "field lens" in the form of an inner solenoid with two half-length solenoids on either end, which permits us to vary independently the focusing power and the absolute rotation imparted by this lens.

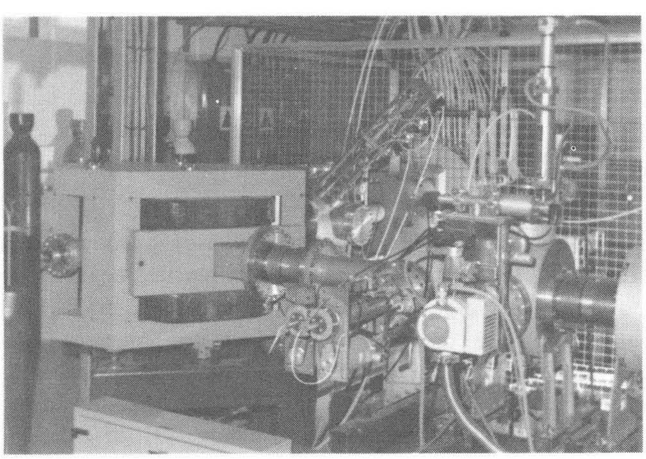

Fig. 3. The first 90° dipole of the "twisted achromat" in the beamline from the ECR source which is visible in the background.

3. THE AXIAL INJECTION BEAMLINE

Matching of the transverse phase-spaces of the beam to the requirements of SPC2 while taking account of the phase-space coupling which can occur in the spiral inflector requires a fairly versatile system. This has been provided by a system of 6 quadrupole magnets,

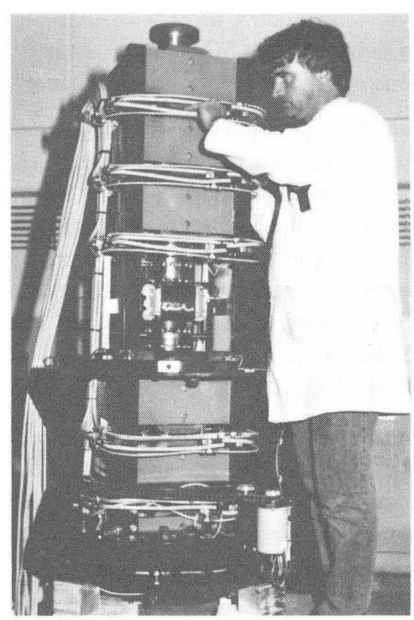

Fig. 4. Rotatable 2-triplet quadrupole telescope, prior to mounting in the axial injection beamline below SPC2.

arranged as two triplets, and mounted in an assembly which can rotate them around the axial injection beamline below SPC2. The completed quadrupole telescope is shown in Fig. 4, prior to installation The entire assembly itself has since been attached to the side of the opening in the 1.25 m thick floor slab, and pivoted so that it can be rotated out of the way to permit components of the axial injection line to be lowered from within the lower yoke of the cyclotron.

Within the cyclotron yoke will be two more solenoid lenses plus an x-y steering magnet and a non-invasive beam centroid detector. The x-y steering magnet is formed using commercially-available laminations for the stator of an electric motor, with two sets of sinusoidally-wound coils, oriented so that their dipole fields are at right angles to each other. A POISSON plot of this magnet can be seen in Fig. 5.

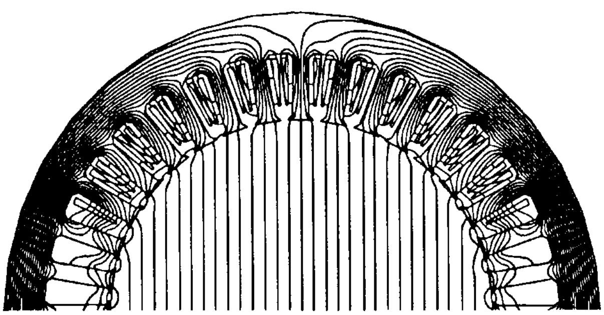

Fig. 5. POISSON plot of the field lines calculated for a sinusoidally wound x-y steering magnet, shown here operating in the x-direction only.

4. THE POLARIZED-ION TRANSFER LINE

The polarized-ion source is also located in the basement, like the ECR source, but with its extracted beam direction aimed towards the axis of the cyclotron projected down to the -3 m level. As shown in Fig. 2, the beamline which transfers the polarized ions into SPC2 joins up with that from the ECR source at the exit waist of the achromatic section discussed above. In order to achieve this, a smaller vertical achromatic system is used, consisting of two 45° dipoles together with several focusing solenoid lenses.

The source itself was supplied together with a solenoid lens just after extraction and a 120° analysing dipole magnet, used as a diagnostic tool to optimize the extraction of the analysed mass-1 beam by using a Faraday cup and a diagnostic "harp". For transfer into SPC2, the dipole B1H will be switched off so that the polarized beam can proceed through the dipole undeflected, until the waist formed by the solenoid L1H is reached. (An aperture here will also remove some of the unfocused mass-2 particles.) A pair of solenoid lenses L2H and L3H will then transport the beam to another waist, where a Wien filter will be located, followed by a second pair of identical solenoids L4H and L5H.

Thereafter the beam enters the achromatic system comprising two outer solenoid lenses and two 45° dipoles, with a solenoid "field lens" located at the symmetry point, *i.e.* in the middle of the 45° section. As before, the field lens is tuned so that the system is properley achromatic. The field lens is also divided into two halves, wired in series but with opposite polarities, so that no net rotation is imparted to the plane of dispersion. This trick is also used for the three solenoid lenses which lie between the Wien filter and the 45° dipoles, in order to preserve the direction of the polarization vector, discussed below.

4.1 Vertically Polarized Beams

The beam from the polarized ion source is polarized along the extracted beam axis, either forwards or backwards. The axis of polarization will then precess in the 45° dipoles. Polarized protons will precess through 251.4 degrees, while deuterons precess through 77.2 degrees. The Wien filter (or crossed-field analyser) will permit us to add to (or subtract from) the precession, by an appropriate amount, without deviating the beam from its path, so that when the particles reach the vertical axis of the injection system, the polarization vector is vertical. This vector is not expected to precess much in the axial fields of either SPC2 or the SC. The successive pairs of triplets of quadrupole lenses in the "high-energy" beamlines should also have limited depolarization effects, as they should tend to cancel out, preserving the "up" or "down" direction of the vertically polarized beam until the target is reached.

4.2 Polarization in the Horizontal Plane

There is no space available in the vertical section of beamline beneath SPC2 for a second Wien filter which could rotate the axis of polarization into the horizontal plane at any specified angle, and another approach was therefore needed. The solution chosen is to allow the Wien filter in the horizontal section of beamline leading from the polarized ion source to rotate. This can then serve in the normal way, as described above, for delivering a vertically polarized beam, and can also provide us with a horizontally polarized beam. For any arbitrary angle of polarization required in the horizontal plane in the vertical injection beamline, we can then calculate (a) the angle of rotation of the Wien filter (*i.e.* of the plane of polarization) about the horizontal beam axis, and (b) the angle of rotation of the polarization axis in the Wien filter.

As the particles traverse the vertical achromat, the polarization vector precesses about the direction of the magnetic field in each of the two 45° dipoles, so that the resultant vector ends up in the horizontal plane, and at the required angle. The subsequent solenoid lenses, and the axial dipole fields of SPC2 and the SC, as well as any dipole magnets encountered *en route* to the target area, will then cause the polarization vector to precess. For a horizontal vector this means that the vector will simply rotate in the horizontal plane, arriving at some angle on target, which can then be altered simply by changing the Wien filter's parameters.

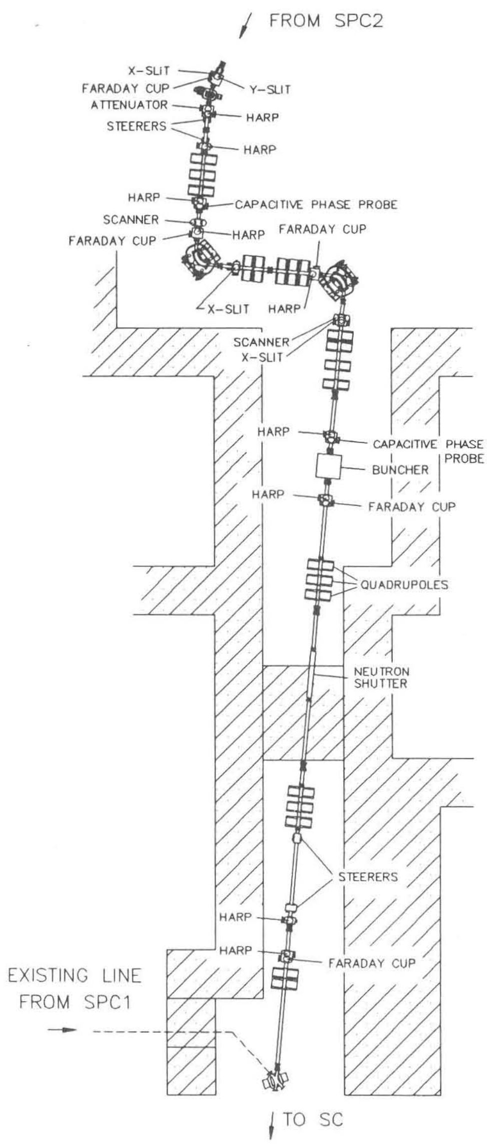

Fig. 6. The transfer beamline between SPC2 and the sector cyclotron, which joins the existing transfer beamline from SPC1.

5. TRANSFER FROM SPC2 TO THE SC

The beamline from SPC2 to the SC is shown schematically in Fig. 6, and is divided both physically and functionally into several sections. A triplet of quadrupole lenses prepares the beam initially by focusing it to a waist at the entrance to a zig-zag dipole achromat. The latter consists of two 90° dipole magnets, with a quadrupole doublet telescope between them, in order to provide the additional x and y waist needed to make the system non-dispersive. An analysing slit at the first waist makes provision for energy-selection, while another quadrupole is placed at the second waist to steer the dispersed particles correctly so that the system is achromatic. Diagnostic "harps" and scanners will be used together with Faraday cups for beam profile monitoring, as in the existing beamlines.

After the achromat, a non-symmetric arrangement of four quadrupoles reduces the divergence of the beam so that it can be transported (*via* a 2-triplet quadrupole telescope) down a tunnel alongside the existing injector cyclotron. A new buncher located in this section will be used together with the existing buncher in the next section of line to provide longitudinal phase-space matching to the SC. The beamline then passes through a shielding wall, and joins the existing beamline linking SPC1 and the SC. Matching of the transverse phase-spaces to the injection requirements of the SC will be carried in this latter section of the line, as is done at present with beams from SPC1.

All the magnets for this beamline have been manufactured, and the line is at present being built up. All the beam transfer systems discussed in this paper are on schedule for completion in time for accelerating the first beams in SPC2[2]

6. REFERENCES

1) Botha, A.H. *et al.*, "Operation and development of the NAC accelerator facilities", in **Proceedings of the Twelfth International Conference on Cyclotrons and their Applications** (World Scientific, Singapore, 1989) pp. 80-83.

2) Du Toit, Z.B. *et al.*, "Progress with the NAC injector cyclotron for heavy and polarized ions", these Proceedings.

3) Conradie, J.L. *et al.*, "Tranfer beamlines for ECR and polarized-ion sources for a new injector at NAC", in **Proceedings of the Twelfth International Conference on Cyclotrons and their Applications** (World Scientific, Singapore, 1989) pp. 376-379.