The KVI cyclotron

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CHAPTER SIX

Summary and concluding remarks

The work described in this thesis has been initiated by the demand from experimental nuclear physicists for higher energies of ion beams from the KVI cyclotron. This has led to the decision to build an axial injection system, because with such a system new types of ion sources, too large to be positioned in the central region, could be used. The energy of heavy ion beams is expected to increase because these new sources can deliver ion beams with a higher charge state. For heavy ions such a system has the additional advantage that because of an increased transmission through the cyclotron on account of better vacuum conditions higher intensities can be obtained. For light ions the diversity with an axial injection system will increase because of the possible installation of a polarized ion source. An increase in the intensity of light ions, produced by internal sources, was foreseen by increasing the extraction efficiency.

The first chapter gives an introduction to the KVI facility. The arguments which have led to the design of the axial injection system will be given, together with a description of the system as it has been installed in 1983.

In chapter two a numerical study is presented for a central region designed to accelerate beams from an external as well as from internal sources. Because of constraints with respect to the injection energy, the location of the axial hole and the choice of the inflector, an axially injected beam is off-centred at the beginning of the acceleration process. The numerical calculations show that it is possible to centre the beam within acceptable limits by the application of magnetic field bumps during the first revolutions. With such a system the radial as well as the vertical motion is favourably influenced. An additional advantage of using field bumps is that beam centring becomes less sensitive to the amplitude of the Dee voltage.

Chapter three describes the influence of several real or equivalent first harmonic effects on the motion of the orbit centre of the beam. Based on knowledge of the motion of the orbit centre the expected current density as a function of radius is calculated and the effect of an off-centred beam on the beam quality is examined. From the calculations it follows that it is important to limit the phase width of the beam, as the phase space area occupied by the orbit centers strongly increases with this width. When the cyclotron is operated with internal sources (for p, d, ^{3}He and α) this is done by means of slits in the central region. In case of axial injection the beam current will in general be so low that phase selection in the central region will not lead to higher external currents. In that case the phase bunching of the injected beam ultimately determines the beam quality.

Beam centring is also a function of the RF phase history of the beam. Acceleration close to the top of the RF voltage is recommended for keeping the mutual difference in the number of turns to a minimum. This may be achieved by means of numerical methods yielding settings for the concentric coils, combined with beam phase measurements at larger radii. In this way also the loss of heavy ion beams through interaction with rest gas is minimized.

An experimental method by which a median plane error can be found is described in the last section of chapter three.

The extraction of beams from the cyclotron is the subject of chapter four. An experimental study is described in which the factors determining the extraction efficiency have been studied. Because the emittance of the beam should not be larger than the acceptance of the extraction systems it again is important to limit the RF phase width of the beam. As a result high extraction efficiencies may only be expected when the phase width is limited, for example by slits in the central region. Measurements have shown that the shape of the septum of the original extractor is not optimal and that the acceptance of the channel is only partly used. Another result is that it is important to introduce radial focusing in the fringing field as soon as possible after the electrostatic channel in order to prevent beam loss and to preserve linear optics.

From experiments with a second extractor, which includes a radially focusing electromagnetic channel directly after the electrostatic channel, a large improvement of the extraction efficiency has been obtained. With this device it has also been shown that beams with the maximum magnetic rigidity can be extracted from the cyclotron.

Experiments with axially injected beams are the subject of chapter five, where it is shown that the acceleration of initially off-centred ion beams is entirely feasible. With the ECR-source coupled to the axial injection system higher intensities and energies for heavy ion beams are easily obtained. A change of energy can be obtained in a fast way by varying in principle only all the electrical parameters linearly with the charge state of the injected beam. Also stable operation of the whole system for periods of many days has proven to be well possible.

An important tool for beam diagnostics has been found in the measurement of gamma rays, which originate from positions where beam loss occurs. Throughout this study this was done with a scintillator/photomultiplier combination. By timing the signals against a signal derived from the RF voltage, information has been obtained on the phase history of the beam, on the phase width of the beam and on the location along the extraction path where beam loss occurs. Also adjusting a remotely controlled slit for optimizing phase selection, is facilitated by employing such measurements. Time resolutions of 1 ns are easily obtained with the equipment used, which corresponds to a spatial resolution at extraction radius of about 7 cm at 10 MHz.

With the installation of the axial injection system the power of the KVI cyclotron has grown considerably. Operation of the cyclotron with heavy ion beams up to Argon has become possible with reasonable transmissions. Physics with low energy non-accelerated heavy ion beams is possible when the cyclotron is producing light ion beams with internal sources. With the installation of an polarized ion source the variety of ions beams at the KVI will still increase in near future.