DESIGN STUDY OF A NEW CENTRAL REGION OF THE PRINCETON UNIVERSITY AVF CYCLOTRON FOR HIGH-QUALITY N=2 BEAMS

M. Yoon+
Dept. of Physics, Princeton University
Princeton, New Jersey 08544, USA
and
S.Oh
Dept. of Physics, University of Manitoba,
Winnipeg, Manitoba R3T 2N2, Canada

Recently we completed a design of the second-harmonic (*i.e.*, N=2) central region of the Princeton University AVF cyclotron which will replace the existing one. The study for this new central region was motivated from the fact that the single-turn extraction for N=2 beams has never been satisfactory in our cyclotron. Through the beam orbit dynamics studies, it was found that the problem was due to the combination of an over-sensitive phase-dependent orbit centering error and large energy spread at the position of radial beam defining slit. In the new design, we reduced these problems. This paper will describe the design procedure and result.

Introduction

The group of Princeton University AVF cyclotron facility is now going to launch the long-term upgrade projects of the cyclotron. These projects include: rebuilding the rf system to boost the reliability of the cyclotron, upgrading the extraction system to increase power dissipation limit, building the internal heavy ion sources (i.e. up to $^{20}Ne^{6++}$) that can be accessed through the bottom plug of the cyclotron, increasing the stability of the rf power supply by employing the computer control system, and finally placing the new second-harmonic (i.e. N=2) central region in order to enhance the energy resolution of the extracted beam. Some of these topics are briefly mentioned in ref. [1]. In this paper we discuss only the design study of the new N=2 central region.

Beam Dynamics Study

The initiation of beam orbit study for the Princeton cyclotron described in this paper dates back in 1985 when we launched a feasibility study for converting the cyclotron for axial injection of ions [2]. The design study of an axial injection system had to be incorporated with the design study of the new central region of the cyclotron. So far, we have completed the design of the axial injection system and the new N=1 central region. See ref. [2] for more details. The study then continued further in order to design a new N=2 central region that will also be associated with the axial injection system.

During the design study for N=2 central region, however, it was found that the existing N=2 central region produces too much orbit centering error. In Fig. 1 we show the radial orbit centering for the existing N=2 central region. This figure represents the precessional motion of the deuteron particle's orbit center as averaged over each turn up to 80 orbital turns. The horizontal axis is along the center of the dee-gap line (i.e., along the radial probe). The origin of the plot is the geometrical center of the cyclotron. The centered orbit then means that the precessional amplitude (from now on we term this as the orbit centering error) is kept within 0.5 mm. Fig. 1, however,

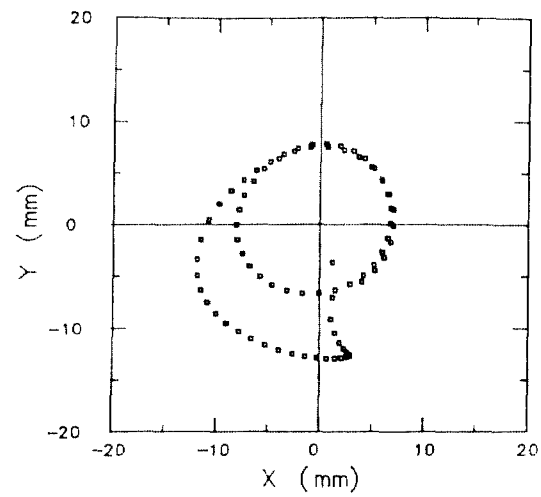

*Fig.*1 Motion of the beam orbit center in the exisitng N=2 central region. Each square represents the orbit center as averaged over one complete orbital turn.

indicates that the existing N=2 central region yields as much as 8 mm orbit centering error when there is no first-harmonic correction field. Even though we allow the effect of electric gap-crossing resonance in our cyclotron, the error of 8 mm is apparently too much (for example, the centering error for 48 MeV proton in the N=1 central region is about 3.5 mm). As will be described later in this paper, this centering error can be reduced by slightly modifying the geometry of the central region.

Further study of the radial motion of the deuteron beam was carried out and its result revealed that the existing N=2 central region has much more severe problem, namely "too

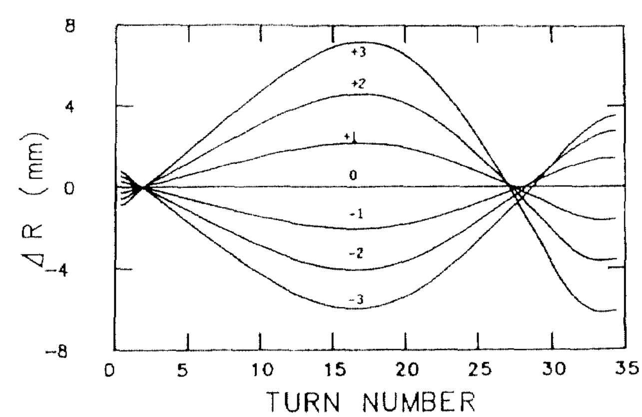

*Fig.*2 Radial displament of the 28 MeV deuteron particles as a function of the orbital turn number. It is seen that for ±2 degree phase the displacement is as much as 8 mm.

much phase-dependent radial orbit dispersion". This is illustrated in Fig. 2 where we depict the radial orbit displacement of particles with respect to the reference particle's position as a function of the orbital turn number. From Fig. 2, we see that for particles with ± 1 degree phase difference with respect to the reference particle's rf phase, the radial displacement at the position of the first phase-selection slit (i.e., around 17^{th} turn) is about 4 mm. Furthermore, the displacement increases to 8 mm for the ± 2 degree phase difference. The turn separation of the reference particle at the position of the first phase-selection slit is approximately 12 mm. This means that the turns are already overlapped before entering the first phase-selection slit. This explains why it has been so difficult to achieve single-turn extraction for N=2 beams in our cyclotron.

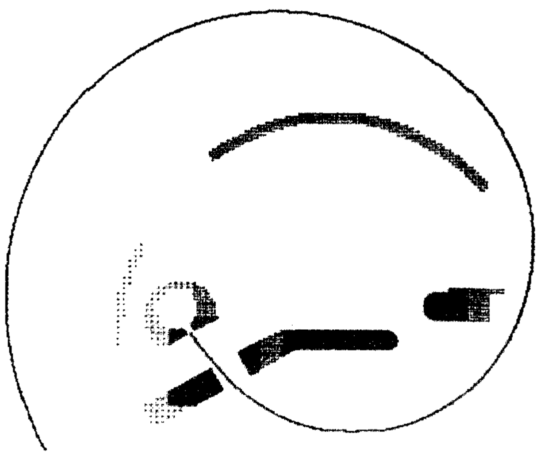

*Fig.*3 Newly designed N=2 central region geometry and the reference particle trajectory.

These effects were reduced significantly in the new design with increased Dee voltage (by 1.5 times) as outlined in our upgrade proposal [3]. However, operating our cyclotron with increased Dee voltage means that the maximum obtainable energy for N=2 beam is limited to about 20 MeV for deuterons while the exisitng central region was designed to produce these particles up to 28 MeV. In order to improve the beam orbit dynamics for N=2 beams covering the full energy range, a further study was undertaken, without including a Dee voltage increase. The results of this study are described below.

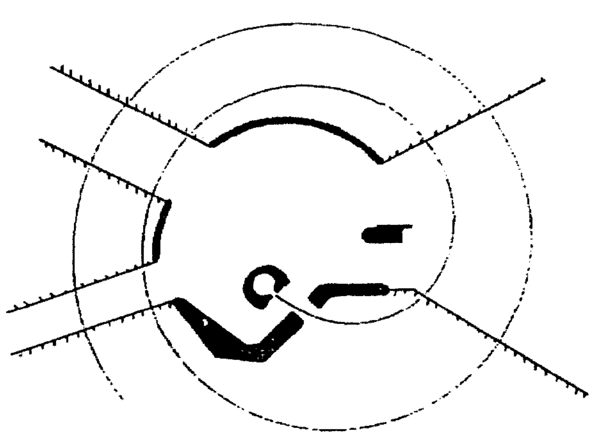

*Fig.*4 Existing N=2 central region geometry and the reference particle trajectory.

A New N=2 Central Region

Fig. 3 shows the geometry of the final design. For comparison purpose, we show in Fig. 4 the geometry of the exisiting N=2 central region. The difference between these two plots is the location of the ion source and the puller tilt angle. The main reason for reducing this puller tilt angle in Fig. 3 is to reduce the radial dispersion mentioned above. This can be seen from Fig. 5 where we illustrate the radial displacement of particles as a function of the orbital turn number. If we compare Fig. 5 with Fig. 2, we immediately see the superiority of this new central region; for ± 1 degree rf phase difference the radial displacement is decreased to 2 mm (our goal is to select the phase within ± 1 degree). The maximum displacement occurs at the 17th turn (i.e., r=20.22 cm) which is nearly the same as in the existing central region.

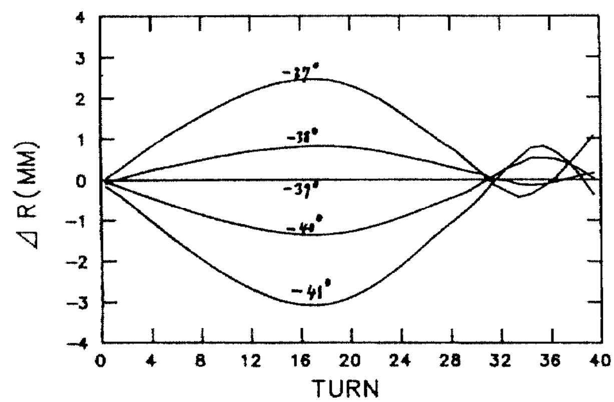

*Fig.*5 Radial displacement of the 20 MeV deuteron particles as a function of the orbital turn number. It is seen that for ± 1 degree phase the displacement is about 2 mm.

Relocating the ion source also results in reducing the orbit centering error. Fig. 6 shows this. In this figure we plot the orbit centering error for a 20 MeV deuteron whose initial rf phase is −39 degree. This figure is the same type of plot as Fig. 1. By

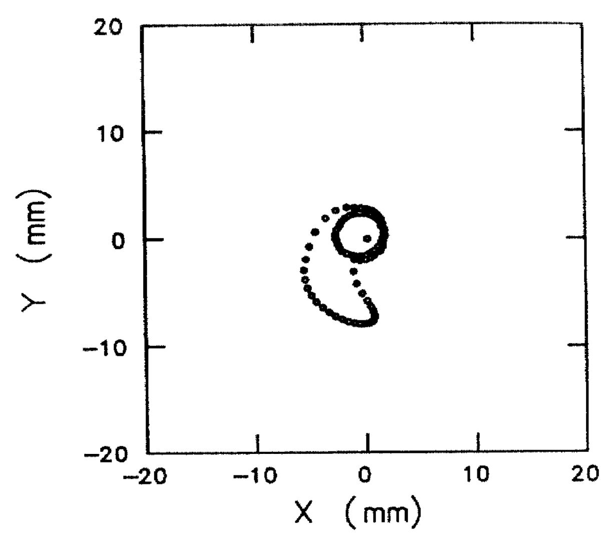

*Fig.*6 Motion of the beam orbit center in the newly designed N=2 central region. By comparing this plot with Fig. 1 one can see that the orbit centering error in the new central region is reduced to about 2.5 mm.

comparing Fig. 6 with Fig. 1, we see that the newly designed N=2 central region yields much smaller centering error; about 2.5 mm.

The axial motion in the new central region was also investigated and the result is shown in Fig. 7. This figure depicts the two orthogonal particle trajectories off the median plane. These two particles form the two marginal rays whose phase space area is 120 mm mrad. It is shown in this figure that the axial motion is well confined in the vicinity of the median plane of the cyclotron.

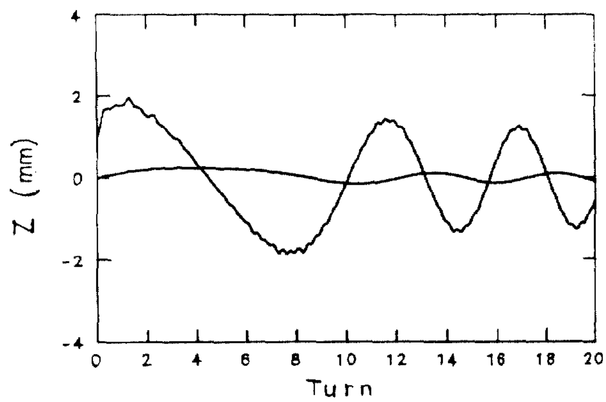

*Fig.*7 Two particle trajectory in the newly designed central region off the median plane. It is seen that the motion is well confined in the paraxial region.

Summary

As a result of the work described above, we now have an improved design, capable of single-turn extraction and improved energy resolution for the full N=2 energy range. In addition, we have a design with increased Dee voltage capable of providing increased intensity for a broad range of energy. The proposed improvements to the extraction region will enable both designs to provide clear, single-turn extraction with improved energy resolution.

References

[1] S. Kidner et. al, Upgrading Projects of the Princeton University AVF Cyclotron, Proc. 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, Japan, October 1986, 113-115

[2] Moohyun Yoon and Saewoong Oh, A Study for Design of the New N=1 Central Region of the Princeton University AVF Cyclotron, NIM, A264 (1988) 135-146

[3] Princeton University Cyclotron Upgrading Proposal, Submitted to the NSF, August, 1987

+ Now at Argonne National Laboratory, Bldg. 360, 9700 S. Cass Avenue Argonne, IL 60439