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THE DESIGN OF THE CENTER REGION OF MSC230 CYCLOTRON

V. Malinin†, D. Popov, O. Karamyshev. T. Karamysheva[1], I. Lyapin, A. Sinitsa
Joint Institute for Nuclear Research (JINR), Dubna, Russia
[1]also at Federal Research Center "Computer Science and Control" Russian Academy of Sciences, Moscow, Russia

Abstract

MSC230 is an innovative efficient medical superconducting cyclotron for the study and investigation of the conventional proton and FLASH therapy, developed by JINR for its new biomedical research center. The machine has an internal injection system provided by a PIG ion source and, for better efficiency, 4 RF dees connected in the center. Despite these restrictions, it is possible to create a center region design which allows initial acceleration with minimal losses sufficient for the FLASH therapy. The design and its features presented in this talk.

INTRODUCTION

MSC230 cyclotron's project is expected to be implemented in the next few years by the joint efforts of Joint Institute for Nuclear Research (JINR, Dubna, Russia) and Efremov Institute of Electrophysical Apparatus (NIIEFA, St. Petersburg, Russia) [1].

JINR has been developing such medical cyclotrons as C400 and C235 together with IBA. And the CS200 cyclotron, together with the Institute of Plasma Physics in China, which was successfully launched recently. The MSC230 accelerator should become a source of an intense proton beam. It is a part of a planned modernization of the equipment of the Medical-Technical Complex at JINR. It is required to increase the current for the possibility of FLASH therapy. An important advantage of using a cyclotron is a sufficiently high beam intensity for FLASH therapy. This is a promising method of therapy that can significantly reduce damage to healthy tissues. In addition, this allows to reduce the number of necessary procedures and work with types of cancer that are not treatable by conventional therapy. Compared to radiation therapy at a conventional dose rate (1–7 Gy/min), FLASH irradiation is performed at a dose rate ~ 100 Gy/s. In order to deliver 100 Gy/s, extracted beam current should be at least 10 μA [2].

When developing the MSC230, we focused on the closest analogues - C235 and Varian. The goal was to take the best from both projects. Such as low magnetic field in the center, constant gap between sectors, sufficient for ESD, superconducting winding, 4 resonators operating at the 4th harmonic. Therefore, the MSC230 design aims for the following features: low power consumption, high beam quality, reduced engineering effort and complexity, rather small size and weight of the accelerator.

Central Region of SC200

The successful launch of the SC200 cyclotron was mentioned in the introduction. The project of the SC200 center was proposed by JINR. In the recent experiments an internal beam of 350 nA was achieved. The internal beam current is in good accordance with calculations (400 nA internal current was predicted).

However, this design had problems, caused by the high magnetic field in the center (3 T): the bump design makes the field in the very center below isochronous, causing the lagging particles at the beginning to lag even more (the phase reached 60°), if the lag is too large, there is not enough acceleration. This was solved by varying the size of the gaps in the center to increase the efficiency of proton extraction from the source while at the same time trying to avoid breakdowns. The experience of designing SC200 was useful in designing the new MSC230 cyclotron.

CENTRAL REGION OF MSC230

The project was developed in such a way that the following tasks were solved:

- Ensuring the possibility of forming a well-centered beam (less than 1 mm offset at a radius of 100 mm), consistent with the acceptance of the accelerator. Phase acceptance ± 20° RF.
- By varying the position of the accelerating gaps, we have to ensure sufficient vertical focusing by the electric field in the first or second turn.
- Minimization of the possibilities of breakdowns.

Two different center region designs are offered (operating with the same RF system). The first is an axially symmetrical design of the central region (see Fig. 1), the second is an optimized central region design developed for reducing the variation in the kinetic energies of the particles (shown in Fig. 2).

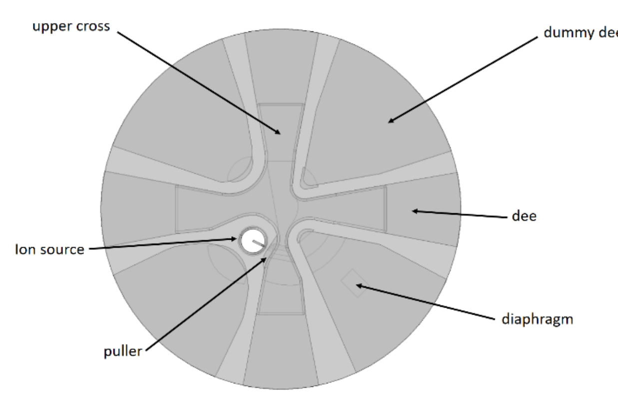

Figure 1: Structure of the central region: axially-symmetric version.

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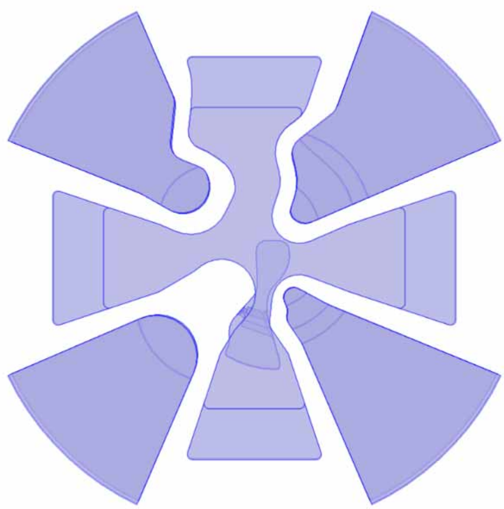

Figure 2: Structure of the central region: optimized version.

Improving Beam Parameters

The results of the phase acceptance calculation for the two versions are shown in Fig. 3. The total transmission through the central region turns out to be about 15% for optimized and 10% for symmetrical. That is, both options provide a sufficient beam quality.

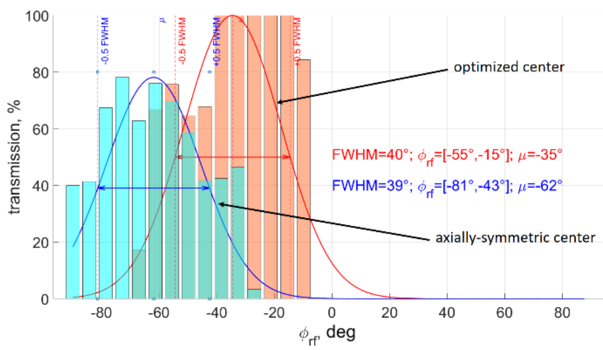

Figure 3: Phase acceptance of the central region– axially-symmetric (orange)/ cyan - optimized (cyan).

Figure 4 shows the dependence of the phase shift on the angle for the two versions of the central region. Positive phase corresponds to lagging particles.

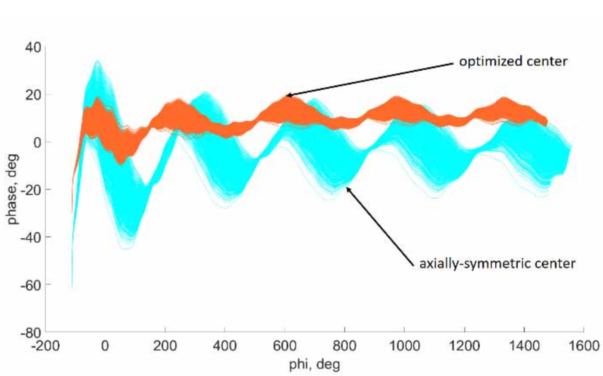

Figure 4: Phase shift in the central region– axially-symmetric (orange)/ cyan - optimized (cyan).

To provide vertical focusing, we create a bump (radial gradient) of the magnetic field (80-100 Gauss). Magnetic focusing caused by the decreasing magnetic field begins after a radius R = 30 mm, the average magnetic field along the radius is shown in Fig. 5 (top).

For R< 30 mm the accelerating electric field provides vertical focusing of lagging particles. The vertical motion of the particles is shown in Fig. 5 (bottom).

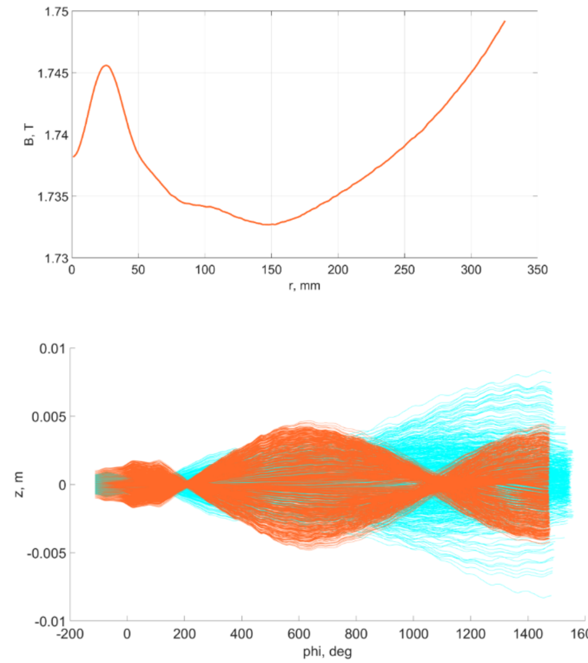

Figure 5: Average magnetic field along the radius (top) and vertical motion (bottom) of the particles in the central region (axially-symmetric (orange)/ optimized (cyan)).

Good vertical focusing and reduction of the variation in phase shifts helps to reduce the energy variation of the accelerated particles, therefore improving beam quality. Figure 6 shows the variation in the kinetic energies of the particles at R = 10 cm, for the two central region designs. The variation for the optimized version is significantly lower.

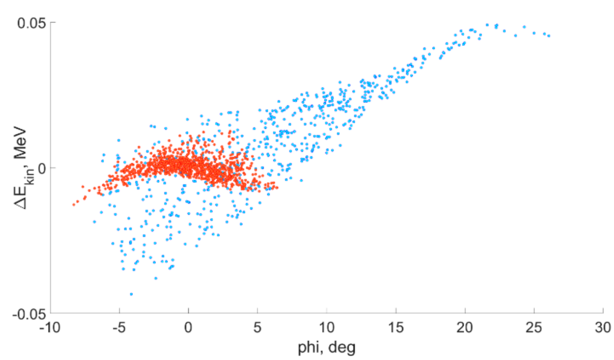

Figure 6: Variation in the kinetic energies of the particles at R = 10 cm. Axially-symmetric (orange)/ optimized (cyan).

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CONCLUSION

The design of the central region of the MSC230 was presented in this talk. Axially-symmetric and optimized designs we compared: optimized design has better beam properties (lower phase shift variation, lower energy gain variation). Axially-symmetric central region design can be used for RF tuning, optimized version works with the same RF system and has better beam properties. Simulation shows good phase acceptance, making it possible to reach beam intensity, required for FLASH therapy.

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