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# Design status of 35 MeV cyclotron magnet for metal radioisotope production

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## 1. Introduction

RFT-30 cyclotron is a 30 MeV proton accelerator as proto-type machine, which was developed and optimized with domestic technology [1, 2]. Metal radio isotopes (RI), such as Zr-89, Cu-64/Cu-67, Ge-68, etc., could be produced successfully by using proton beam of RFT-30 cyclotron [3-4]. Needs and market of metal RI production have been increased, so that the domestic RI production system including domestic cyclotron design is focused for a business model.

The cyclotron technology has been developed for a long time, and various cyclotron models were designed with proper applications [5]. Most cyclotrons, which have energy specification about 30 MeV, were developed by using these conventional structures, and major models were launched by Ion Beam Application and Advanced Cyclotron System Incorporation. RI production is one of main application, and the maximum energy of cyclotron depends on the cross section of nuclear reaction for RI. The germanium-68 has been used for both a source of the gallium-68 generator and calibration source of radiation devices [6]. Natural gallium can be used as a target material with p-n reaction for the Ge-68, and the proton energy 30 MeV has good advantage for the production yield due to the cross section [7]. The melting point of gallium material is about 29 degrees, so the sealing design should be considered in order to irradiate proton beam with efficient energy to the target [8]. Therefore The 35 MeV proton energy was selected for new cyclotron model with Ge-68 production based on feasibility study in our group.

The new version of cyclotron has conventional design structures, such as sector focused magnet, vertical half-wave resonator and external ion source. The magnet of 35 MeV cyclotron has similar design structure with RFT-30 cyclotron, however some structures are considered carefully such as vertical hill gap, extracted hill radius and magnet weight, etc.. This paper introduces the conceptual design of 35 MeV cyclotron magnet. The important design parameters are explained, and the design status of magnet is descripted.

## 2. Design concept

The 35 MeV cyclotron has the purpose of metal radio isotope, and primary design specifications are similar to RFT-30 cyclotron. The maximum energy, particle species, beam current are considered as 35 MeV, proton accelerator, 300 μA, respectively. These parameters were selected with operating experiences of RI production by using RFT-30 cyclotron system. Negative hydrogen ion will be accelerated for two stripping extraction system, and the multicusp ion source will be used with spiral inflector for high beam current emission.

The sector focused magnet is applied for new version of cyclotron, and the design concept is same with RFT-30, such as parameters four sectors, azimuthal varying field, circular pole shape. The new cyclotron has higher energy than RFT-30, so the radial dimension should be treated carefully because of magnet weight. Magnet size is dominant value for total weight of cyclotron, and it could be constraint condition economically. The new version IBA 30 MeV cyclotron was changed with higher revolution frequency from 16.25 to 18.75 MHz, so compact magnet could be applied for reduction of magnet weight and price. Although higher revolution frequency has advantage of magnet size, our cyclotron keeps the same frequency 16 MHz with RFT-30 system. A difference of revolution frequency also be related to radio frequency and isochronous magnetic field. We have many kinds of try and error experiences to RF system (cavity and amplifier) at 16 MHz revolution frequency, so it could be useful advantage for development of RF cavity with same radio frequency to RFT-30. The higher revolution frequency increases the isochronous magnetic field, so the magnet design requires the sensitive structure for the beam orbit. The cyclotron magnetic field almost be reached to the nonlinear range of hysteresis curve in the surface of iron, so that the manufacturing process is more difficult to match the isochronous magnetic field by magnet structure.

## 3. Initial design of main magnet

The design of magnet is first step in the cyclotron design phase. The isochronous magnetic field can be expressed in equation 1.

$$B_0 = \frac{m_0 \omega}{q} \qquad \text{Equation 1}$$

where $m_0$ is rest mass, $q$ is charge, $\omega$ is revolution frequency. Basic parameters can be extracted by equation 1, such as extraction radius, average magnetic field at the particle energy. It assumes that there is no consideration of magnet sector, so isochronous orbit is circular shape. The initial magnet structure is designed based on the RFT-30 magnet. Table 1 shows the magnet specification.

Table I: Design specification of magnet

| | RFT-30 | New design |
|---|---|---|
| Maximum energy [MeV] | 30 | 35 |
| Yoke radius [mm] | 1350 | < 1750 |
| Yoke height [mm] | 1440 | < 2000 |
| Pole radius [mm] | 810 | < 1000 |
| Valley gap [mm] | 620 | < 1000 |
| Hill gap [mm] | 30 | 50 |
| # of sector | 4 | 4 |
| Hill angle [deg] | < 48 | < 55 |
| Rev. frequency [MHz] | 16 | 16 |
| Conductor size [mm] | 12 * 12 | 15 * 15 |
| Conductor hole diameter [mm] | 6 | 8 |
| Coil dimension [mm] | 215 * 282 | 250 * 350 |
| Coil power [kW] | 11.3 | ~ 9 |

The primary design conditions were coil power consumption and magnetic field efficiency. The hollow conductor of coil is selected 15 square size to decrease voltage of coil due to secure the margin of magnet power supply. Two cases of magnet diameter and height are shown in figure 1. First design version focused on the magnetic field efficiency and securing maintenance space (pole gap, chamber gap, coil gap, etc..). Second version was designed in terms of decreasing the total weight of magnet.

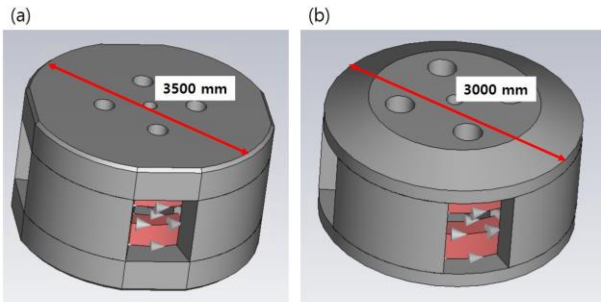

Fig. 1. Two cases of magnet drawing (a) yoke radius 1750 mm, height 2000 mm, weight 120 tons, (b) yoke radius 1500 mm, height 1700 mm, weight 70 tons

The magnetic field was obtained by Tosca code in CST-Ms [9] in figure 2. The case 1 design is higher efficiency of magnetic field at the yoke and pole, where pole gap is 50 mm. The magnetic field strength is less value than case 2, so the magnetic field at pole can be more generated.

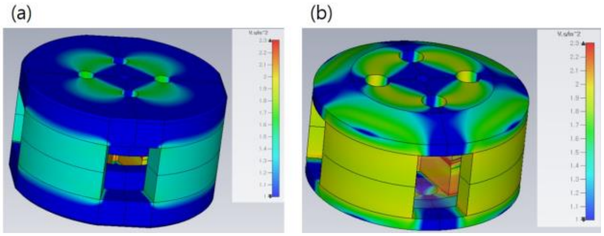

Fig. 2. Magnetic field distribution (a) case 1 (b) case 2

The magnetic field strength at yoke position is lower than case 2 because of higher thickness of yoke, but total weight of magnet is almost 120 ton. Both two cases, the magnetic field is generated over the isochronous magnetic field at accelerating position, two design could be satisfied for beam orbits. However, because of the magnet weight, about 70 tons, the design of case 2 was selected for detail modeling.

The design of magnet should be considered with installation space of injection beam line, extracted beam line, vacuum chamber and RF cavity. These other components are designing for conceptual design of 35 MeV cyclotron, and initial design parameters are based on RFT-30 drawing. However, the extracted beam line is different to RFT-30 cyclotron. Two switching magnets have been installed at the side yoke in the RFT-30, and we found interference of magnetic field between switching magnet and main magnet due to the sharing yoke structure. The new version of magnet is selected separated switching magnet.

## 4. Conclusion

The 35 MeV cyclotron is designing to product metal radio isotopes. The maximum energy was selected as 35 MeV with target consideration of mass production for germanium-68. Primary design concept was decided as an AVF cyclotron based on RFT-30, however main design parameters are optimizing with operation and maintenance experiences of RFT-30. The outline design of cyclotron magnet is performing now, and two cases of magnet drawing was checked. For magnet total weight, yoke radius and height were chosen 1500, 1700 mm, respectively, and magnet weight was about 70 tons. The magnetic field was simulated by TOSCA code, hill and valley structure will be optimized in the next design phase.

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