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Electromagnetic Design of Wobbler Using Halbach Dipole Magnets for KOMAC RI Production Beamline

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1. Introduction

It plans to produce various radioactive isotopes using 100-MeV proton beam obtained from KOMAC proton linac [1]. The proton beam obtained at the end of the linac is transported to the target room using dipole electromagnets and quadrupole electromagnets, and it is irradiated on the RI production target to make various radioactive isotopes. Since the proton beam power reaches tens of kW to produce large amounts of radioactive isotopes, it is necessary to increase the size of the proton beam to a size similar to the RI production target. For this purpose, a wobbler should be installed, but in the case of the KOMAC RI beamline, it is impossible to install the wobbler using electromagnet due to the very limited space. To solve this problem, Halbach dipole magnets were decided to be used [2].

2. Design

2.1 Modification of RI production beamline

The beam diameter at the target is expected to be approximately 10 mm if the beam is irradiated using the current beamline. In addition, if there is a mismatch between the beam center and the target center, and the increase in the beam diameter due to the beamline errors, it is expected that the beam diameter on the target will exceed 30 mm. The target size is 30 mm. Therefore, it is necessary to reduce the beam diameter on the target. The simple method is to install another quadrupole magnet just before the penetration into the target room. In this modified case, the beamline quadrupole magnets can be adjusted appropriately to reduce the beam diameter on the target by 2 mm as shown in Figure 1. When wobbling such a reduced diameter beam reduces the heat power density and unnecessary beam loss, it is very advantageous for RI production. At present, the installation of this quadrupole electromagnet has been completed, and is preparing for beam test.

2.2 Electromagnetic design of wobbler

Keeping the gap between the two dipole magnets 47 mm results in a wobbling diameter of 15 mm, about one-half the target size. The maximum magnetic field at the center of the magnet is 5.2 kG. The wobbler must be rotated, and this generates eddy current in the metal beam pipe inside the hollow cylinder magnets, and the eddy current produces magnetic field and distorts the magnetic field by the wobbler magnet.

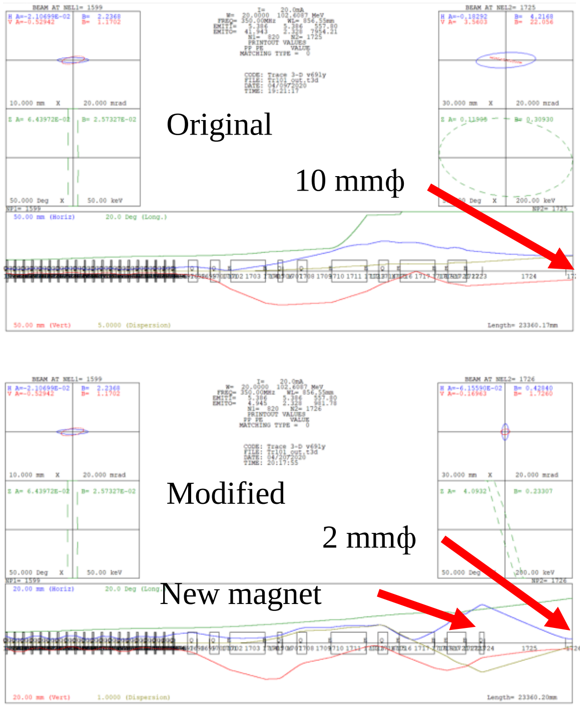

Fig. 1. Beam optics of RI production beamlines

The eddy current increases as the electric conductivity of the beam pipe material decreases and the rotation speed of the magnet increases. Therefore, the magnetic field induced by the eddy current should be estimated according to the electrical conductivity (σ) of the beam pipe material and the rotation speed (ω) of the magnet. As shown in Figure 2, assuming an infinite alternating magnetic field, the magnitude of magnetic field induced by the eddy current can be obtained as follows.

$$\Delta B_{max} = 4\int_0^{\pi/2} \frac{\mu_0 \sigma t}{2\pi}\omega B_0 \sin^2 \phi \, d\phi = \frac{\mu_0 \sigma t}{2}\omega B_0$$

As the material of the beam pipe, ceramics (requires conductive coating on internal surface), Inconel, etc. are better, but stainless steel was selected in consideration of price and manufacturing difficulties. In the case of stainless steel bellows, it is possible to have a thin thickness, but it was selected as a circular pipe because of concerns about the vibration of the beam pipe inside the rotating magnet. Considering the demand for mechanical strength for vacuum, the thickness of the beam pipe is 2.1 mm. In this case, it was determined that when the dipole magnet was rotated at 180 rpm, the eddy current induced magnetic field was less than 5% of the external magnetic field, and the beam could be wobbled without any problem.

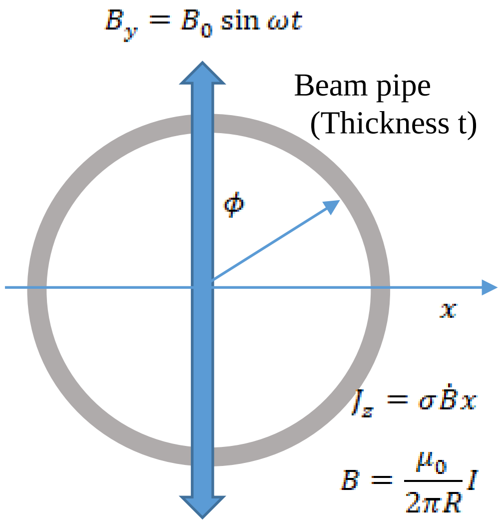

Fig. 2. Magnetic field assumed for eddy current calculation

2.3 Mechanical design of wobbler

The Wobbler consists of two hollow cylindrical Halbach-type permanent magnets with a mass of 21.88 kg, an inner diameter of 115 mm, an outer diameter of 240 mm and a length of 110 mm. The inertial moment of these two magnets is 0.3872 kg·m^2, and when rotated at 180 rpm, the rotational kinetic energy is 68.8 J. Therefore, even a motor of around 100 W can be operated sufficiently, but considering the surrounding conditions such as radiation environment and difficulty in maintenance, 400-W geared motor with speed reduction ratio of 1/10 was decided. The power of the motor is transmitted to the magnet by means of pulleys with one-half reduction ratio and a V-belt. Figure 3 is the schematic of the wobbler.

3. Future Plan

Based on this design, we are making the wobbler. This device is difficult to install and remove due to the limited space of the target room, and it must be operated continuously for a long time in a high radiation environment. Therefore, if it is considered that it can be sufficiently reliable by conducting a test run at the stand first for a long time, we will proceed with the actual installation. The goal is to obtain beam time by the end of this year and conduct test operation for RI production.

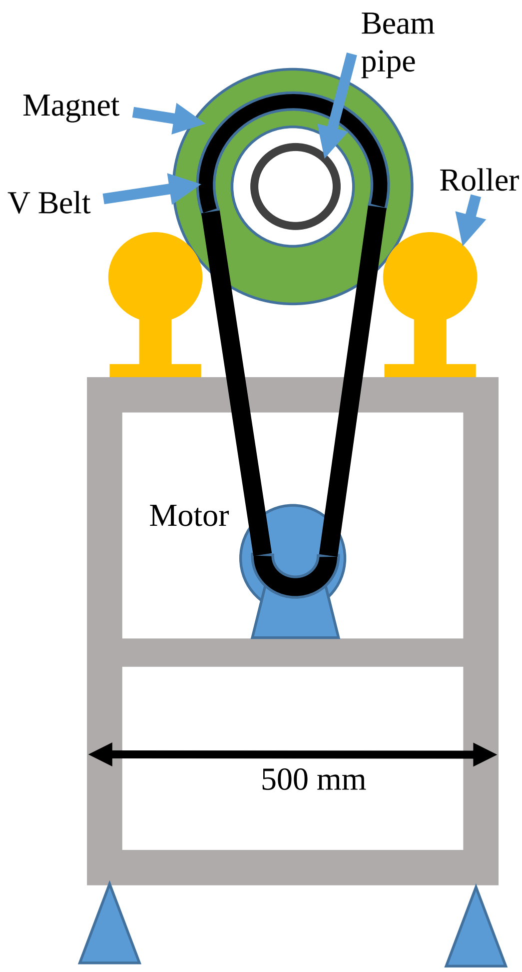

Fig. 3. Schematic of wobbler

ACKNOWLEDGEMENT

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[1] Kye-Ryung Kim, et al., "Medical RI Development Plan of KOMAC", Journal of the Korean Physical Society, Vol. 71 (2017).

[2] Yong-Sub Cho, et al, “Basic Design for Wobbling System of KOMAC RI Beamline Using Halbach Dipole Magnets”, Transactions of the Korean Nuclear Society Virtual Spring Meeting July 9-10, 2020.