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

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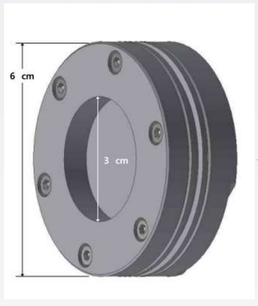
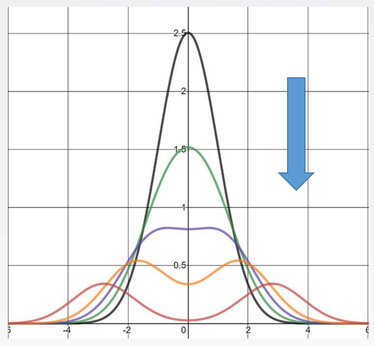
Wobbler using Halbach Dipole Magnets for RI Production Beam Line @ KOMAC 100-MeV Proton Beam

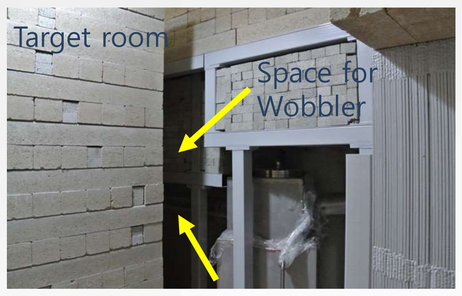


RI production target
(1.5 cm radius)

Preventing target damage by high power proton beam and Improving utilization of target are important.



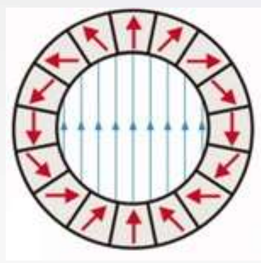
Using wobbler,
- Reduce peak power
- Improve uniformity
- Minimize beam loss

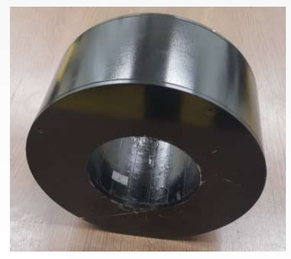


Only <100 cm long, <50 cm wide wobbler is accessible

Absolutely out of space
⇒ Wobbler should be installed in target room
⇒ Electromagnet wobbler is impossible

∴ Need a wobbler with rotating permanent magnets
And as simple as possible considering installation, radiation environment, and maintenance

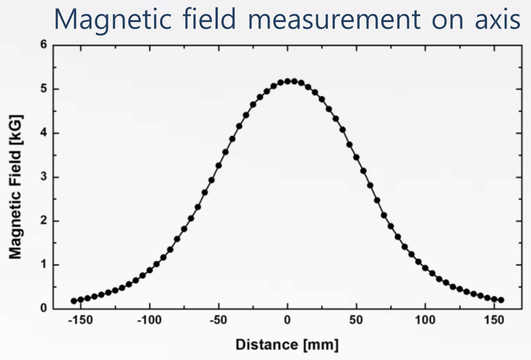




Halbach Dipole Magnet to be used

Halbach Dipole Magnet :
Consisting of small permanent magnets, outer magnetic field is almost zero.

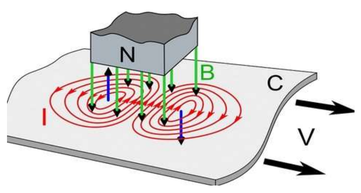
Magnetic field measurement on axis



B · L = 0.0689 T·m
⇒ 2.7° bending for 100-MeV proton
⇒ If proton moves forward 150 mm, it moves 7 mm in transverse.

Electromagnetic Design: Eddy current in Beam Pipe

Beam pipe of existing RI beamline is made of stainless steel with a diameter of 100 mm to minimize proton beam loss.
Applying rotating dipole magnetic field to this stainless steel beam pipe induces eddy current.

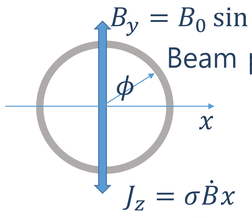


Eddy current can be reduced using ceramics or bellows, but the existing beam line needs to be modified.
Therefore, use stainless steel pipe and instead rotate at low rotation speed at which effect of eddy current is negligible.

Estimation of magnetic fields induced by current
: Simulate the rotating magnetic field as Z-direction infinite AC magnetic field

$B_y = B_0 \sin \omega t$

Beam pipe (thickness = 2.1 mm)



$J_z = \sigma \dot{B} x$

$B = \frac{\mu_0}{2\pi R} I$

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

$\sigma = 1.45 \times 10^6 S/m$ (Stainless steel)

$\omega = 2\pi \times 3Hz$ (180 rpm)

$\frac{\Delta B_{max}}{B_0} = 3.4\%$ (Acceptable)

Z direction is finite, so it is expected to be smaller in practice.
After production, off-line experiment will be carried out to verify.

Basics to rotate wobbler magnet

Motor :
- Rotation speed = 3 Hz
- Moment of Inertia = 0.3874 kg·m² (Magnet mass 21.88 kg, x 2ea.)
- Kinetic Energy @ 3 Hz = 68.8 J

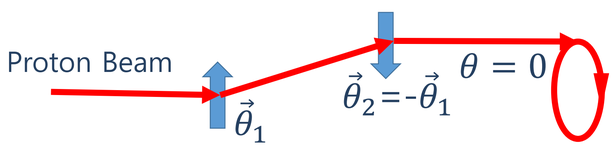
⇒ 100 W motor is sufficient, but 400 W considering durability.

Rotation Speed
- Geared motor (360 rpm = 6Hz)
- Pulley and V-belt (reduction ratio = 2:1)

Magnet support
- Nylon rollers for downward
- V-belt for upward

Mechanical Design and Fabrication of wobbler

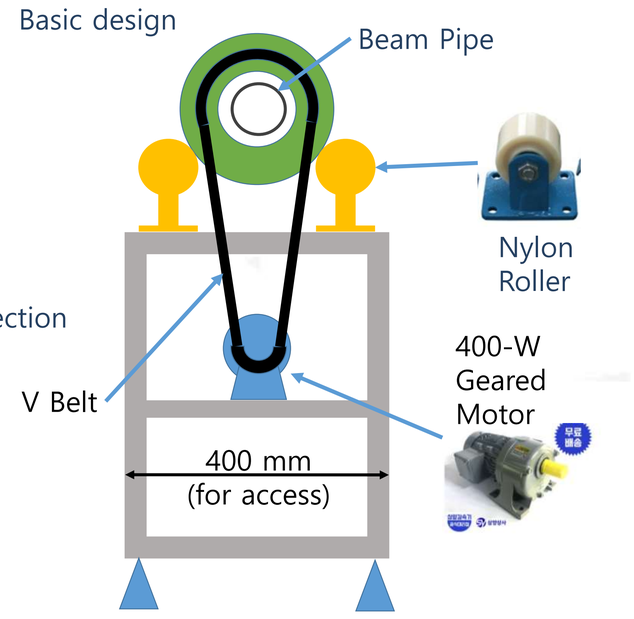
Two rotating dipole magnets with 180° polarity from each other

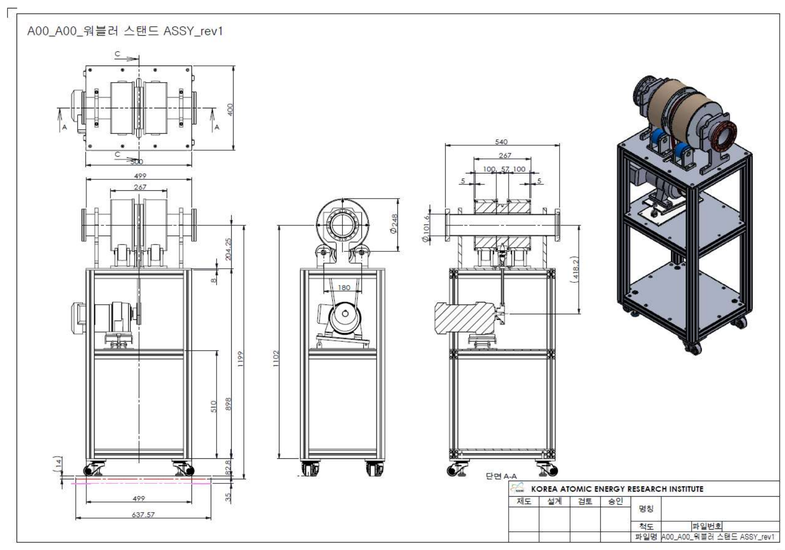


Advantage:
wobbling radius is constant along beam direction
⇒ Decided to use this method.

※ The biggest drawback of permanent magnets is " impossible to turn off."
And always a beam shift.

Basic design





Fabrication drawing

Wobbler under factory test

Status and Future Plan

Wobbler waiting installation

- Wobbler required to reduce peak power and improve uniformity on RI targets
- Due to space limitations, Halbach magnets wobbler to be installed in the target room
- Width of wobbler < 500 mm for installation
- Wobbler rotation speed to be 3 Hz due to eddy current in stainless steel beam pipe
- According to design, wobbler fabrication completed
- Off-line test operation completed and performance verified
- Wobbler waiting for installation at target room shielding door
- Plan to install wobbler for future experiments irradiating high power beams to targets