Magnets in Accelerator System

M. Jeong*, Pohang Institute of Science and Technology, Pohang, Korea

Abstract

Magnets are used for deflection, focusing/defocusing, and correction of trajectory of charged particles. Hence, fabricating and testing these magnets is an necessary procedure in the design of accelerators. In this report, the magnetic field of the magnet was measured by a Hall sensor.

INTRODUCTION

In an accelerator system, magnets are used for manipulation of charged particles, such as deflection and focusing. Hence, producing and testing these magnets is an essential procedure in the design of accelerators.

In this report, the magnetic field of the magnet was measured by a Hall sensor.

THEORETICAL BACKGROUND

Normal Conducting Magnets

For charged particles, Lorentz force is defined by (1).

$$\vec{F} = q(\vec{E} + (\vec{v} \times \vec{B})) \tag{1}$$

In electron accelerator, electron bunch moves in relativistic velocity. This suggests that the magnitude of electric field required to deflect the electron beam is larger than that of the magnetic field by a factor of the speed of light. Therefore, a dipole magnet is commonly used for the deflection of an electron in the accelerator.

Magnet can be also used for focusing of electron beams. In an acclerator system, a quadrupole magnet(see Fig. 1.) is typically used for focusing and defocusing of the electron beam. For quadrupole, gradient of magnetic field $B' = \partial B_y/\partial x = g$ is constant. This property makes quadrupole capable of focusing electron beam. However, if beam is horizontally focused by quadrupole, it is vertically defocused. Thus, quadrupole triplet is used to focus the beam in both horizontally and vertically.

The solenoid can be used to focus beams, but due to a relativistic effect, it can be used only when the electron energy is low.

The focal length of the quadrupole is proportional to the inverse of $\gamma\beta$. That is, focal length is dependent to the energy of electron beam. This effect is called chromaticity. To correct this chromaticity, sextupole magnet is placed at the downstream of the focusing quadrupole. Magnetic field of sextupole is proportional to x^2, so chromaticity effect can be corrected by sextupole. Sextupole is nonlinear elements that can affect beam lifetime and injection efficiency in a storage ring. Their use is essential but their effects must be evaluated.

* msjeong@postech.ac.kr

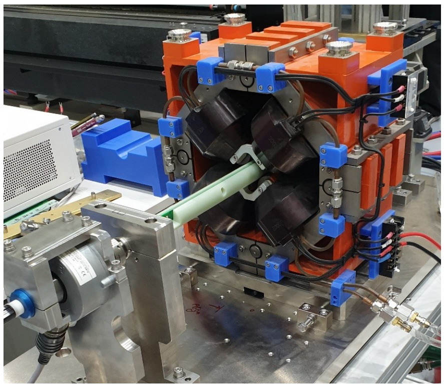

Figure 1: Quadrupole.

Superconducting Magnets

For normal conducting magnet, maximum magnitude of the magnetic field is limitied to 2T due to Ohmic loss. Thus, to reach higher magnetic field, employing superconducting magnet is required. Material such as Nb-Ti is used for superconducting magnet. Since superconductivity is limited by not only temperature but also current density and magnitude of magnetic field, superconducting magnet is operated in the temperature lower than Curie temperature of the material.

Though superconducting magnet can reach higher magnetic field, it has several challenges. First, quench occurs when superconductivity is lost. Also, cryogenic facility is required to maintain low temperature. Lastly, superconducting coils often have large dimensions, which makes challenges for transporting.

MEASUREMENT OF MAGNETIC FIELD

Simulation of magnetic field of magnets

To evaluate the magnet before manufacturing, computational simulation is conducted. The simulation is operated magnetic multipole model, which is based on modeling the magnetic potential as

$$F = \vec{A} + iV \tag{2}$$

. If there is no current, the Laplacian of F is (3).

$$\nabla^2 F = \nabla^2 \vec{A} - \nabla(\nabla \bullet A) + i\nabla^2 V \tag{3}$$

By Maxwell's equation, $\nabla \bullet \vec{B} = 0$ and $\nabla \times \vec{B} = 0$. Thus, if we introduce Coulomb gauge, i.e. $(\nabla \bullet A = 0)$, $\nabla^2 F = 0$. Therefore, $F = \vec{A} + iV$ satisfies Maxwell equation when there is no current.

If there is current $\vec{J}$, then by Ampere's law, $\nabla \times \vec{B} = \mu\vec{J}$. If B is given by B=$B_x + iB_y$, then its conjugate form is $B^* = B_x - iB_y = idF/dz = i(\partial F/\partial x dx/dz + \partial F/\partial y dy/dz) =$

$\partial F/\partial y - i(-\partial F/\partial x)$. Thus, it satisfies $\nabla^2 F = -\mu J_z$. Therefore, $F = \vec{A} + iV$ also satisfies Maxwell equation when there is a current source.

Hall sensor

Hall sensor is a sensor which is used to measure magnetic field. By Hall sensor, magnetic field can be converted into electric signal. The figure of Hall sensor is shown in Fig. 2. In Fig. 3), the magnetic field measured by Hall sensor with respect to horizontal, vertical, and longitudinal positions respectively.

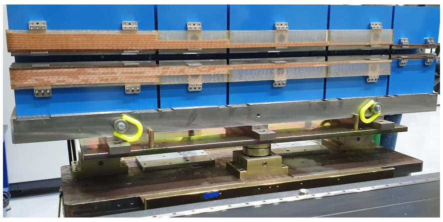

Figure 2: Hall sensor in PAL.

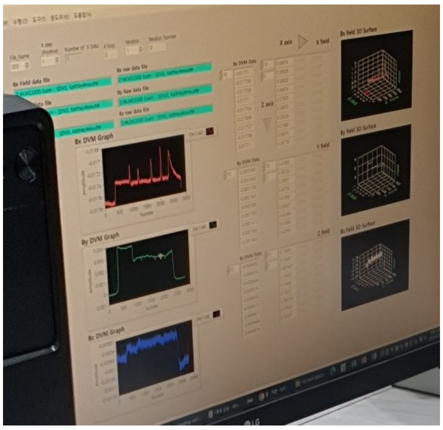

Figure 3: Magnetic field measured by Hall sensor.

The magnetic field of magnet is calibrated by standard electromagnet(See Fig. 4).

CONCLUSION

In this report, I covered how the magnets in the accelerators were designed, measured, and calibrated.

REFERENCES

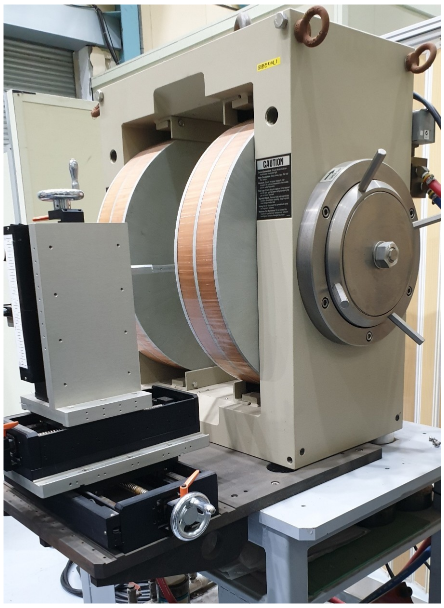

Figure 4: Standard electromagnet in PAL.