Design and Construction of Dipole Magnets for New Beam Line

Y.Sakemi,K.Hatanaka,K.Nagayama,S.Morinobu,T.Itahashi,M.Kibayashi,
S.Ninomiya,T.Saito,K.Sato,A.Tamii,H.Tamura,K.Tominaga,and M.Uraki
Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan

We need to realize the high uniformity of magnetic field within $\Delta B/B \sim 10^{-4}$ for the beam diagnosis with the new beam line. According to the optics calculation, the beam size is enlarged to 120 mm in the dipole magnet BA2 in the dispersive mode as shown in the previous report. So the design goal of the dipole magnets is set to realize the requested uniformity in the region of ±60 mm with respect to the central track. The gap size 70 mm is same as the existing dipole magnets of the beam transport line. The maximum magnetic field in the gap is 14 kG, which is enough to bend the various particles including heavy ions extracted from AVF cyclotron.

To save the mount space and construction cost, we decided to add shims to the edges of pole pieces to achieve the uniform magnetic field in the large region with the relatively compact magnet. The thickness and size of the shim and cut size of edges are adjusted to realize the required field uniformity. The design of the magnets has been done by three dimensional field simulation code OPERA-3D. All the geometrical details of the magnet such as the shape of pole pieces, curvature of pole edges, and field clamps are included in the three dimensional model. We put the shim anti-symmetrically in each side of the pole piece to have the symmetric field distribution along the central track as far as possible. We can get the uniform field distribution in the required region 120mm within the range of used magnetic field from 7 kG to 13 kG as shown in Fig.1, which is the simulation result of OPERA-3D.

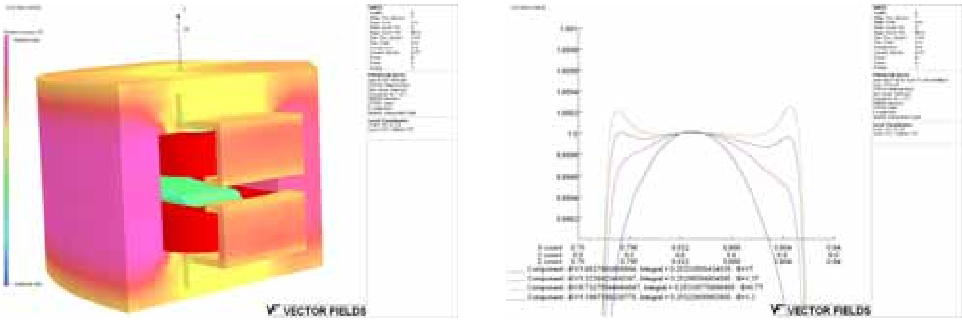

Fig.1. The left figure show the 3-d magnet field distribution. The right plot shows the field distribution of B(r)/B(r=0) at 7,9,12, 13kG. The uniformity becomes worse as the field becomes higher.

At the entrance and exit edges of the magnets, the corners of the pole pieces have been shaped in a Rogowski's curve. The field clamps are designed to fix the distribution curves of the fringing field. The parameters such as the clamp size and plate thickness are adjusted to locate the Effective Field Boundary (EFB) at the pole face position with the 3 dimension magnetic field simulation. We put the curvature of the pole piece edge in the upstream side of BA2, where the dispersion becomes large, to adjust the second order optics matrix element (|) minimum to get the focal plane vertical with respect to the beam direction. Other edges of dipole magnets BA1/2/3 are made flat, although those flat edges also make an effective curvature, and we should take into account them in the optics design of the beam line. Optimization of the geometrical parameters in the magnet design has been done at the magnet field 10 kG, where we will use most frequently for the high resolution beam tuning.

The measurement results of the dipole magnet BA2 are shown in Fig.2 together with the OPERA-3D simulation results. The designed field uniformity is achieved in the constructed dipole magnet, and it can be seen that the shims added in the pole edges work well to enlarge the uniform field region in the magnet. The uniformity becomes worse as the field becomes higher however we can keep the sufficient uniform region of ±50 mm at the highest field of 13 kG. The EFB for the poles with flat and curved edge are also evaluated from the measurement of field distribution around edges. The EFB realized in constructed magnets has almost same value as the designed one. We have effective curvature in the EFB in the flat pole edge of dipole magnets BA1/2/3, and these curvatures are included in the final realistic beam optics calculation.

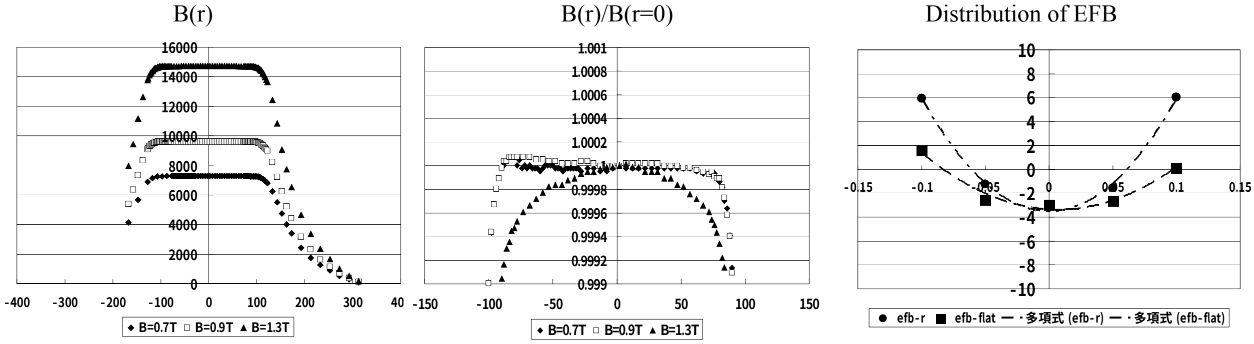

Fig.2. The left plot shows the position dependence of the magnet field distribution at 7,9,and 13 kG. The length of pole piece is 300 mm, and we can obtain a wide uniform field distribution. The middle plot is the magnified field distribution. The tight plot is the position dependence of EFB. The circle is for the curved edge, and square for flat.