DIPOLE MAGNET DESIGN FOR A BUNCH COMPRESSOR*

T. Kanesue, L. P. Chau, D. Noll, O. Meusel, and U. Ratzinger,
Institute of Applied Physics, Frankfurt University, Max-von-Laue Str. 1, 60438 Germany

Abstract

The Arc Magnetic Dipole chicane with Large Aperture Longitudinal Focusing Cavities (ARMADILLO) is a bunch compressor under construction for the FRANZ neutron source at Frankfurt University. It will compress 9 intense micro bunches of a 2 MeV, proton beam accelerated by a 175 MHz linac into one 1ns short pulse at the neutron production target with repetition rate of 250 kHz. In the bunch compressor, two homogeneous dipole magnets and two duplex-gradient dipole magnets will guide the micro bunches, separated by a 5 MHz RF-kicker to individual tracks. The path length of the micro bunches along the bunch compressor are determined based on the bunch center velocity and the linac frequency. The homogeneous dipoles provide a magnetic flux density of 515 mT across all 9 trajectories. In contrast, the gradient dipoles have individual magnet parameters for every micro bunch. The design of the two types of dipoles for the ARMADILLO bunch compressor will be presented.

INTRODUCTION

FRANZ is an intense neutron source using a 2 MeV proton linac as a driver for ^{7}Li (p, n) neutron production. A 50 - 100 ns long proton beam is accelerated and bunched by a cw operating 175 MHz coupled RFQ-IH DTL cavity at a repetition rate of 250 kHz. The ARMADILLO bunch compressor is following after the linac to compress 9 mi Beam dynamics of the FRANZ bunch compressor using realistic fields with a focus on the rebuncher cavities cro bunches of up to 140 mA to one very short 1ns intense beam pulse with a peak current of several amperes at the target. More details of FRANZ can be found in [1].

A layout of the bunch compressor is shown in Fig. 1. The ARMADILLO is a Mobley-type bunch compressor [2], which uses a flight path length difference to achieve longitudinal bunch compression. At the entrance of the bunch compressor, a 5 MHz RF kicker will guide the 9 micro bunches onto individual trajectories. A homogeneous dipole with a uniform magnetic flux density of 515 mT will provide a linear separation of the trajectories. After the trajectories are well separated, the micro bunches will be injected into a duplex-gradient dipole. It will provide an individual magnetic flux density and thus individual bending radii on each trajectory. The magnets will be placed symmetrically as shown in Fig. 1. In total, the bunch compressor consists of four dipoles.

The transverse beam dynamics will be controlled by weak focusing and by edge focusing of the dipoles. Because of the high space charge forces, two RF rebuncher cavities will be installed for longitudinal beam dynamics. The specifications of the dipoles such as bending radius, field gradient, and edge angles were carefully determined to fulfil all of the requirements [3]. The design of the magnets is under investigation using the TOSCA code of OPERA-3D [4].

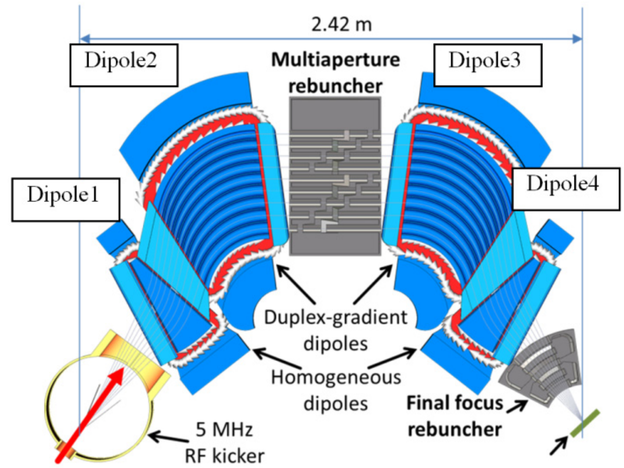

Figure 1: ARMADILLO bunch compressor.

HOMOGENEOUS DIPOLE MAGNET

The specification of the homogeneous dipole is shown in Table 1. Two homogeneous magnets shown in Fig. 1 (Dipole 1 and Dipole 4) are identical H-type dipole with a gap height of 56 mm. The magnet should provide a uniform magnetic field density of 515 mT. Figure 2 shows a simulation model of the first homogeneous dipole. Each magnet has two identical water-cooled coils wound around the upper and lower pole. The coil cross section of 40 mm wide by 150 mm high was used as a conductor cross section. The total height of the magnet is 640 mm.

Table 1: Specifications of Homogeneous Dipole

Parameters	value
Min. gap height	56 mm
Magnetic flux density	515 mT
Bending radius	400 mm
Bending angle	16.6° (beam1) – 28.2° (beam9)

kanesue@iap.uni-frankfurt.de

The relatively big gap height induces a large fringing field, which is undesired for beam dynamics. In addition, a large fringing field can be coupled with that of the neighboring magnet because of the limited space between the magnets. The minimum distance between the beam lines of Dipole 1 and Dipole 2 is about 110 mm. Thus, the fringing field length should be minimized. The fringing field integral, K is a measure of a fringing field. The K is defined as

$$K = \int_{-\infty}^{+\infty} \frac{B_z(s)[B_0 - B_z(s)]}{g B_0^2} ds \qquad (1)$$

where g is the gap height, $B_z(s)$ is the magnitude of the fringing field on the magnetic mid plane at a position s measured perpendicularly the entrance face of the magnet to the point in question, and B_0 is the asymptotic value of $B_z(s)$ well inside the magnetic entrance [5]. The fringing field integral should be less than 0.3, which is the value used for calculations. To reduce the fringing field, a 50 mm thick field clamp was added at the entrance and the exit of the dipole. The effects of the field clamp can be seen in Fig. 3, which shows $B_z(s)$ on the magnetic mid plane along the line perpendicular to the entrance face of the magnet (A- A' in Fig. 2). It suppressed the fringing field integral from $K = 0.42$ to $K = 0.12$.

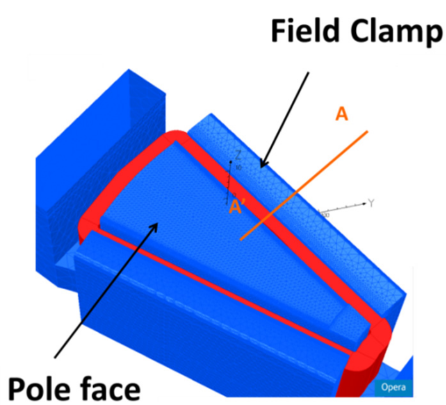

Figure 2: Bottom half of homogeneous dipole magnet.

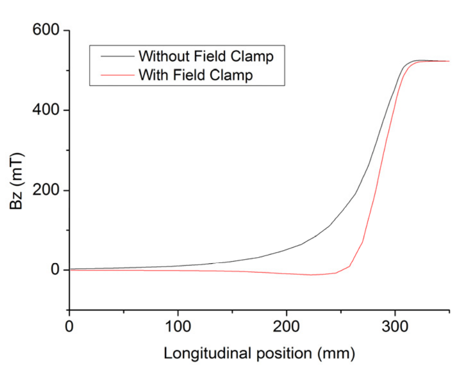

Figure 3: Vertical component of magnetic flux density on magnetic midplane of the homogeneous dipole on the line perpendicular to the magnet side face (A-A' in Fig. 2.).

DUPLEX-GRADIENT DIPOLE MAGNET

The specifications of the duplex-gradient dipoles are listed in Table 2 for the outermost trajectory (beam 1), the central trajectory (beam 5) and the innermost trajectory (beam9), respectively. The duplex-gradient dipoles have two radial magnetic field gradients. One is a global field gradient across the trajectories to merge micro bunches longitudinally. The other is a local field gradient on each trajectory for the transverse focusing of each micro bunch. The special features of the duplex-gradient dipoles are individual edge angles. The edge angles are chosen individually on each trajectory by the beam dynamics to focus the beam transversely and longitudinally on the neutron production target [6]. Figure 4 shows edge angles needed at the entrance of the Dipole 2 in Fig. 1.

A simulation model of the duplex-gradient dipole is shown in Fig. 5. The total height is 1100 mm. The longitudinal dimension should be minimized because of the limited space between the components. The gap height should also be minimized to satisfy individual edge angles. A larger gap height limits the field modelling features of individual beam lines.

A C-magnet equipped with small trim coils for each trajectory has been considered. The main coil has the dimension of 77 mm wide by 134 mm high. The cross sections of the small coils are 5 mm wide by 155 mm high. Assuming on a conductor filling factor of 0.47, the maximum current density in small conductor is 7 A/mm^2, which is feasible for a water-cooled coil. With this concept, the gap height can be kept constant across all apertures. The gap height of 50 mm is used for the design. The fringing field integral of the model is $K = 0.19$ with a 50 mm thick field clamp, which satisfies the requirements. An intensive study on the gap height, field clamp shape, and shimming on the pole tip is under way.

Table 2: Specifications of Duplex-Dipole

Parameters	Beam 1 (outside)	Beam 5 (center)	Beam 9 (inside)
Min. gap height (mm)	50	50	50
Magnetic flux density (mT)	445	509	602
Bend radius (mm)	463	405	342
Bending angle (deg)	81.645	78.266	72.627

ISBN 978-3-95450-115-1

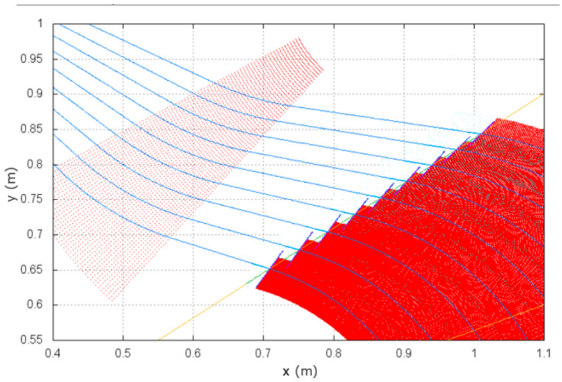

Figure 4: Edge angles needed for Dipole 2 (Duplex-Gradient dipole).

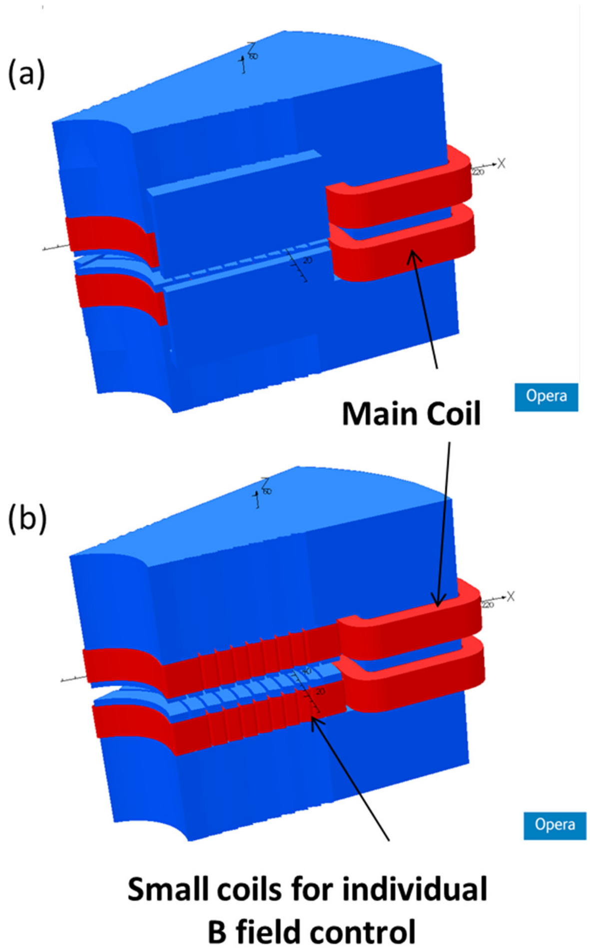

Figure 5: Simulation model of duplex-gradient dipole. (a) is a full model, (b) is a model without field clamps to show individual small coils for each trajectory.

CONCLUSION

The ARMADILLO bunch compressor is the key component to achieve an intense neutron production by a 1 ns long proton beam. In this proceeding, the dipole magnet designs for the bunch compressor are shown. The design of the homogeneous magnets is nearly finished. The intensive work to reach the requirements of the duplex-gradient magnet bunch compressor has been conducted. The final design of the magnet will be completed in the near future.

REFERENCES

[1] U. Ratzinger et al., "The Frankfurt neutron source FRANZ," IPAC'10, Kyoto, Aug 2010, MOPEC059, p. 597 (2010).

[2] R. C. Mobley, Proposed Methods For Producing Short Intense Monoenergetic Ion Pulse, Phys. Rev. 88 (1952) 60.

[3] L.P. Chau et al., "Bunch compressor for intense proton beams," LINAC'10, Tsukuba, Sep 2011, TH203, p. 730 (2010).

[4] Cobham, Vector Fields Ltd, UK.; http://www.vectorfields.com

[5] Karl L. Brown, SLAC Report – 75, June 1982.

[6] D. Noll et al., "Beam dynamics of the FRANZ bunch compressor using realistic fields with a focus on the rebuncher cavities," IPAC'11, San Sebastian, Sep 2011, MOPS030, p. 667 (2011).