TRIUMF Document-117806

Design Note TRI-DN-15-09

Dipole Magnet Requirements for the Nier-spectrometer

Document Type: **Design Note**

Release: **DRAFT** **Release Date:** **2015/00/00**

Author(s): **Suresh Saminathan**

	Name:	Signature:	Date:
Author:	**S. Saminathan**		
Reviewed By:	**R. Baartman**		
Reviewed By:	**F. Ames**		
Reviewed By:	**G. Clark**		
Approved By:			

Note: Before using a copy (electronic or printed) of this document you must ensure that your copy is identical to the released document, which is stored on TRIUMF's document server.

History of Changes

Release Number	Date	Description of Changes	Author(s)
DRAFT	2015-00-00	Initial release	S. Saminathan

Contents

1 Introduction

The proposed charge state breeder for the CANREB facility is an electron beam ion source (EBIS). Energy spread of the extracted beam from an EBIS is relatively high ($\sim$ 100 eV). This limits the mass resolving power of a spectrometer, which has only a dipole magnet. The Nier-spectrometer concept has been used in our beamline design to achieve a high resolving power (200) [1]. The Nier-spectrometer consist of an electrostatic and a magnetic bender. The electrostatic bend (EB) compensates the energy dispersion of the magnetic bend (MB). This allows an achromatic mode of operation resulting in a high mass resolving power even for beams with a high energy spread as in the case of extracted beams from an EBIS. Calculated ion trajectories through the Nier-spectrometer as shown in Fig. 1. The detailed design of the Nier-spectrometer is presented in Ref. [1]. In this document we describe the dipole magnet (MB) requirements for the Nier-spectrometer.

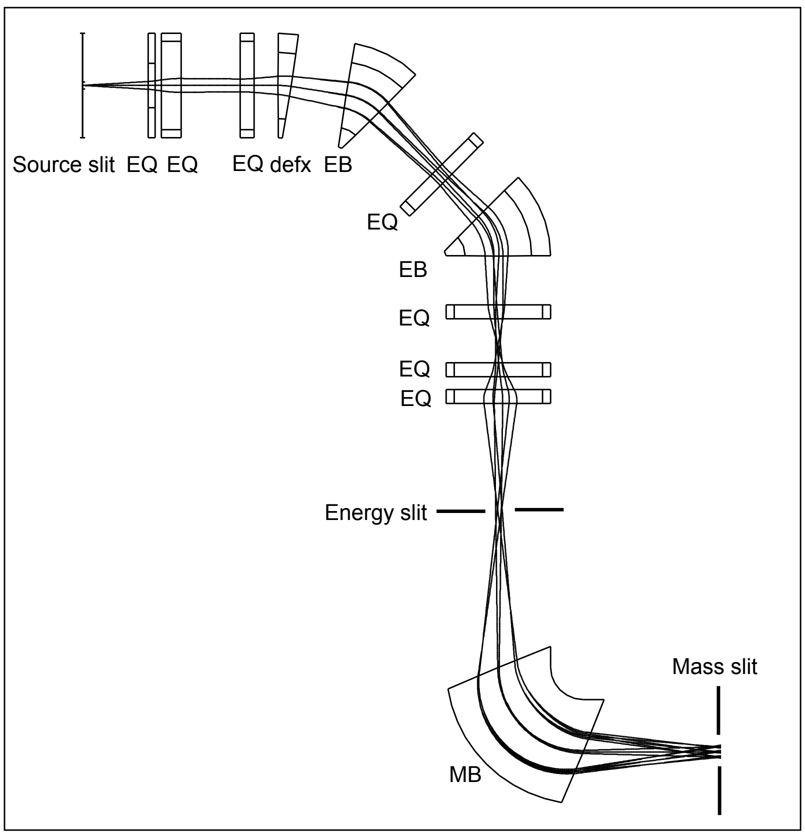

Figure 1: Nier-Spectrometer layout with the calculated ion trajectories (for $\delta_E = \pm$ 0.25 % and $\delta_m = \pm$ 0.5 %) by using up to third-order calculation.

2 Beam parameters

Maximum beam rigidity $(B\rho)_{\mathrm{max}}$	0.204 T m
Normal beam rigidity $(B\rho)_{\mathrm{norm.}}$	0.0322 T m – 0.0451 T m
Minimum beam rigidity $(B\rho)_{\mathrm{min}}$	0.026 T m
Maximal mass deviation (δ_m)	$\pm$ 0.5 %
Maximal energy deviation (δ_E)	$\pm$ 0.25 %
Horizontal half width of the beam [2 rms] (x)	2.0 mm
Horizontal half width of the beam divergence [2 rms] (x')	8.0 mrad
Vertical half width of the beam [2 rms] (y)	2.0 mm
Vertical half width of the beam divergence [8 rms] (y')	8.0 mrad
Emittance [4 rms] (ε)	16.0 μm

Table 1: Beam parameters at the source slit.

3 Basic magnet requirements

Magnet type	Rotated pole face
Bending angle (θ)	90°
Pole face rotation angle (entrance and exit)	22.5°
Bending radius (ρ)	360 mm
Full air gap (Non-bend plane)	60.0 mm
Maximum field strength (B_{max})	≥ 0.566 T
$B(I)$ linearity over the whole range	within $\pm 2\%$ [2]
Field homogeneity $(\Delta \int B\mathrm{d}l)/(\int B\mathrm{d}l)$ (see Fig. 5)	$\leq 4 \times 10^{-4}$

Table 2: Summary of the basic magnet requirements.

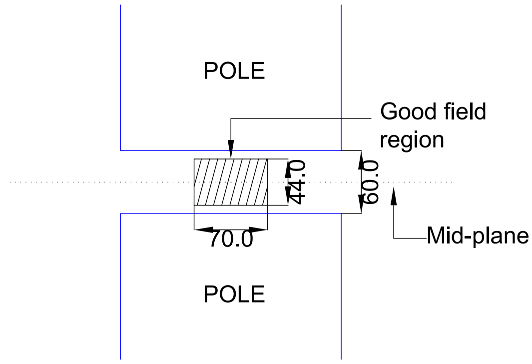

Figure 2: Vertical cross-section at the center of magnet. Measurements in mm.

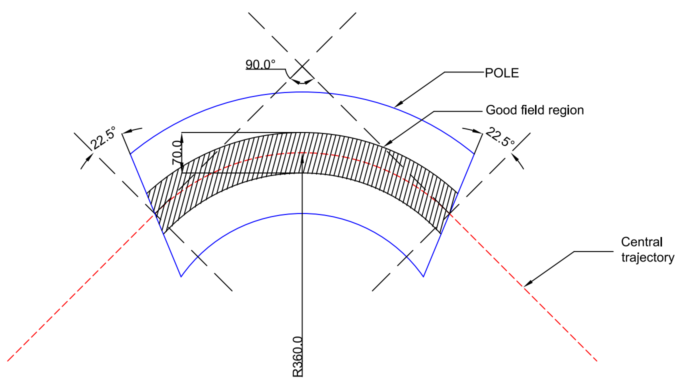

Figure 3: Plan view of the magnet pole in the horizontal plane. Measurements in mm and degree.

4 Aperture size

The so called 'good field region' is determined by a central region around the theoretical beam trajectory, where the field quality has to be within certain tolerances. In our case the good field region is defined as the sum of beam width, margin for orbit displacement (2 mm), margin for a installation/alignment (typically 6 mm).

4.0.1 Minimum pole width (half size)

Maximum 4rms beam size in the bend plane (x-plane) is calculated by using the code TRANSOPTR, which is $\sim$27 mm. The minimum pole width is given by

$$\text{Good field region (half size)} = 35 \text{ [mm]} \tag{1}$$

4.0.2 Minimum pole gap (half size)

Maximum 4rms beam size in the non-bend plane (y-plane) is calculated by using the code TRANSOPTR, which is $\sim$14 mm. The minimum pole gap is given by

$$\text{Good field region (half size)} = 22 \text{ [mm]} \tag{2}$$

5 Beam rigidity

Maximum beam rigidity is defined as

$$(B\rho)_{\max} = \frac{p}{e} = 0.204 \text{ [T m]} \tag{3}$$

6 Magnetic field strength

From the maximum beam rigidity and the required bending radius of the magnet the calculated magnetic field strength ($B_{\max}$) for a dipole magnet

$$B_{\max} = \frac{B\rho}{\rho} = 0.566 \text{ [T]} \tag{4}$$

with ρ being the magnet bending radius in [m].

7 Integral field

From the rigidity and bending angle (θ), the required field integral is:

$$\int_{-\infty}^{+\infty} B\mathrm{d}l = (B\rho)_{\max} \times \theta \simeq 0.31983 \text{ [T m]} \tag{5}$$

The increment dl is taken along the ion trajectory.

8 Field homogeneity

The parabolic distribution of the vertical field in a dipole magnet causes an error in the x-direction momentum [3, 4], represented as

$$\Delta x' = \frac{\Delta \int B_y \mathrm{d}l}{B\rho} \tag{6}$$

where

$$B_y(y=0) = B_{y0}[1 + k2\frac{x^2}{g^2}] \tag{7}$$

g characterizes a width of the parabolic distribution, while k_2 denotes the field inhomogeneity over this region.

We thus have

$$\Delta x' = \frac{B_{yo}L}{B\rho}k_2\frac{x^2}{g^2} = \theta k_2 \frac{x^2}{g^2} \tag{8}$$

where θ is the nominal bend angle and L is the effective length of the dipole.

The TRANSOPTR calculation shows that the intrinsic 2nd order aberrations from a magnetic bender causes an emittance growth about 0.05 %. We ask for the same amount of emittance growth due to the parabolic field component, so we require [3]

$$\Delta x' = \frac{Lx^2}{2\rho^3} \tag{9}$$

From equation 8 and 9, we obtain

$$k2 = \frac{g^2}{2\rho^2} \tag{10}$$

Substituting a good field region of $g = \pm 35$ mm in the bend plane and the bending radius $\rho = 0.036$ m into above equation 10, we get the field inhomogeneity k_2 over this region needs to be $< 4.7 \times 10^{-3}$. We require field inhomogeneity less than factor of 10 smaller, i.e. $\left[\frac{\Delta \int B\mathrm{d}l}{\int B\mathrm{d}l}\right] \leq 4 \times 10^{-4}$.

9 Power supply

9.1 General requirement

- According to Canadian standards (comply to CSA).
- Comply to TRIUMF control standards.
- Requirement for the ripple of the power supply, $\Delta I/I \leq 4 \times 10^{-4}$

9.2 Requirement for the ripple of the power supply

The ripple in a dipole power supply causes a shift of beam axis downstream, represented as [5]

$$\Delta x = \beta_x \frac{\Delta B_y L}{B\rho} \tag{11}$$

where β_x is smoothed β function; about 1.70 m in our case, L is the effective length of dipole, and $B\rho$ is the magnetic rigidity of beam.

We require such a shift to be much less than the beam radius, around 0.001 m (2 rms) at the slit location

$$\beta_x \frac{\Delta B_y L}{B\rho} \leq \sqrt{\beta_x \epsilon} \tag{12}$$

We thus have

$$\frac{\Delta B_y}{B} \leq \frac{\sqrt{\beta_x \epsilon}}{\beta_x} \frac{\rho}{L} = \frac{\sqrt{\beta_x \epsilon}}{\beta_x \theta} \tag{13}$$

where θ is the nominal bend angle of the dipole. Substituting $\sqrt{\beta_x \epsilon} = 0.001$ m, β_x = 1.70 m and $\theta = \pi/2$ into above equation 13, we get $\Delta B_y/B_y = \Delta I/I \leq 3.7 \times 10^{-4}$. This is the constraint for the ripple of the power supply at the normal operating regime.

10 Vacuum chamber [6]

- Material: non magnetic stainless steel.
- Clearance for the beam path in the vertical plane should be at least 44 mm [full gap].
- Clearance for the beam path in the horizontal plane should be at least 70 mm [full width].
- Vacuum $< 4 \times 10^{-8}$ mbar.
- Flanges ConFlat (CF) 100 at entrance and exit. CF 40 in straight ports (see Fig. 4).
- Openings for alignment in both entrance and exit direction should be foreseen.

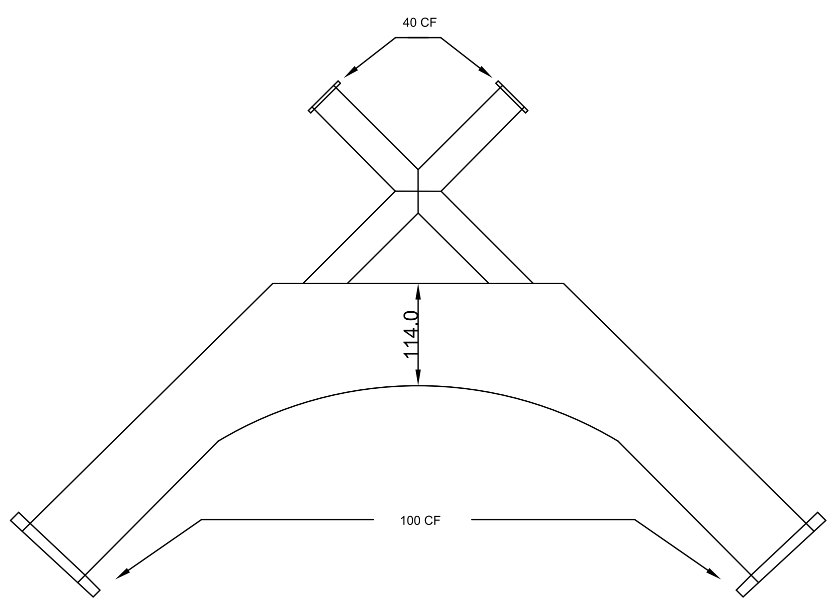

Figure 4: Plan view of the vacuum chamber in the horizontal plane. Measurements in mm.

11 Field Measurement

11.1 Field strength at the magnet center

- It must be checked that the field at the magnet center can reach 0.566 T, and run continuously for three hours.
- We also require a calibration (B vs. I) curve, giving vertical component of the B field at the center of the magnet for at least six different currents while the magnet is ramped up to nominal current, then at least six more points when the magnet is ramped down to zero current. Immediately after, we require the same measurement to be repeated with the opposite polarity [2].

11.2 Field map and integrals

We require a field map in the mid-plane and calculation of straight line field integrals. Proposed measurement procedure:

- Check that the field integral, in the mid-plane, along the central integral path (geometrical trajectory) passing by the center of the magnet exceeds the expected value of 0.32 T m (see Fig. 5).
- In the mid-plane only, measure (map) the vertical field at every 8 mm along the central integral path and also the vertical field at every 7 mm along the direction perpendicular to the central integral path. The required measurement region is shown in the figure 5. This must be done with the field at the center equal to 0.566 T. The field along the central integral path and around the central integral path (i.e. 11 integral path with a spacing of 7 mm between the integral path) may be calculated from the field map and the relative field integral (see Eq. 14) must be within 4×10^{-4} over the width (g) ± 35 mm.

  Relative field integral is defined by

  $$\left[\frac{\Delta \int B dl}{\int B dl}\right] = \frac{\left[\int B \mathrm{d}l\right]_{\text{meas}} - \left[\int B dl\right]_{\text{cal}}}{\left[\int B \mathrm{d}l\right]_{\text{cal}}} \tag{14}$$

  where the $\left[\int B \mathrm{d}l\right]_{\text{meas}}$ is the measured field integral along the each integral path and $\left[\int B dl\right]_{\text{cal}}$ is the calculated field integral for the same integral path. Here the field integral can be measured/calculated according to the region defined in Fig. 5.

  Calculated integral field along the each trajectory is given by

  $$\left[\int B \mathrm{d}l\right]_{\text{cal}} = L_i \times B_{\text{max}} \tag{15}$$

  where L_i is the effective length of each integral path, i.e. $L_i = f(g)$. The effective legth calculation is described in the Appendix. Also TRIUMF may accept other methods to calculate the effective field integral. Other methods must be proposed at bid time and include details of how the calculation will be made.

- If the field integrals satisfy these conditions, and if the magnet is built according to the specified magnet requirements specified in the table 2, then the field quality satisfies our requirements.

- We also want a similar field map showing the residual fields ($I = 0$) done after operating at 0.566 T.

11.3 Data

- TRIUMF to get a copy of all the measured data, including field components and coordinates (indexed against the physical dimensions of the magnet) for each measurement point. Complete material specifications (B vs H curve) have to be given.

- We require a copy of magnet design drawings, Solid work model and also magnet simulations (OPERA3D preferred),

- We require a calibration (B vs. I) curve, giving vertical component of the magnetic field at the center of the magnet for at least five different currents.

12 Magnet delivery

- A proposal for the magnet design with complete material specification (B vs. H curve) and a field map should be given about 2 months after receiving the order.

- Field mapping should be performed before delivery and the results should be provided.

- The magnet delivery time should not exceed 7 months.

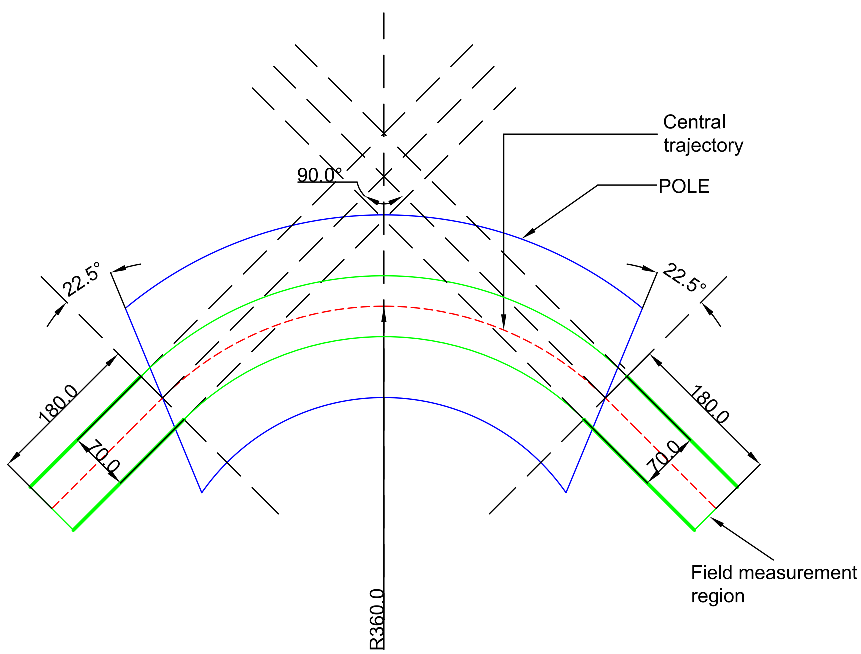

Figure 5: Schematic description of the central trajectories (red dashed line) and measurement region (green solid line) with a magnet pole (blue solid line) in the horizontal plane. Measurements in mm and degree.

13 Appendix [7]

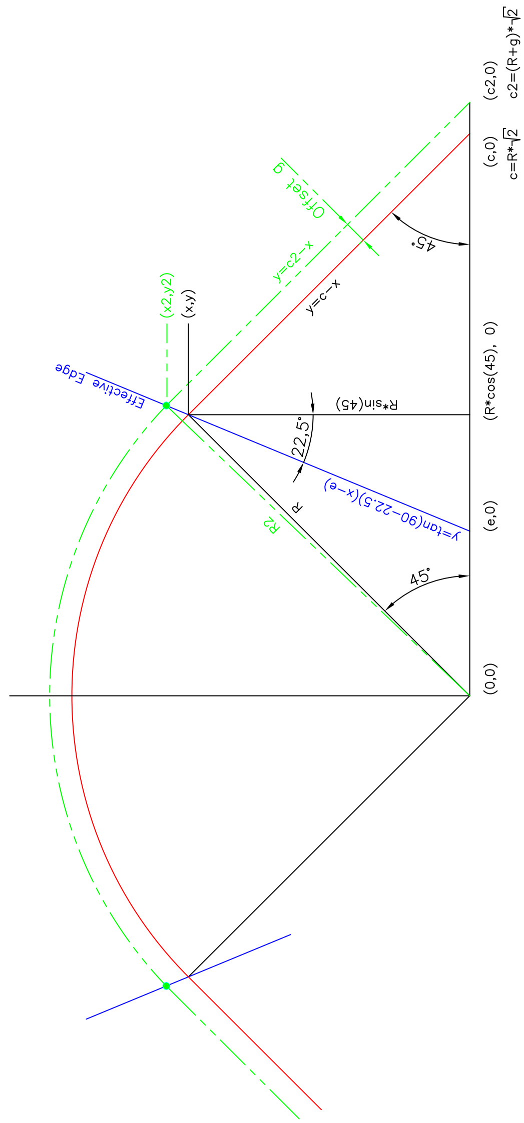

Figure 6: Plan view for calculating the effective legth.

$$c_i = \sqrt{2}(R + g) \tag{16}$$
$$M = tan(\theta - \alpha) \tag{17}$$
$$e = Rcos(\theta) - Rsin(\theta/2)tan(\alpha) \tag{18}$$
$$x_i = \frac{c_i + M \times e}{M + 1} \tag{19}$$
$$y_i = c_i - x_i \tag{20}$$
$$R_i = \sqrt{x_i^2 + y_i^2} \tag{21}$$
$$L_i = 2R_i \left(\frac{\pi}{2} - atan2(x_i, y_i)\right) \tag{22}$$

where, R is the nominal bending radius (360 mm)
θ is the nominal bending angle (90°)
α is the edge angle (22.5°), and
$i = f(g)$, g (mm) = [-35, -28, -21, -14, -7, 0, 7, 14, 21, 28, 35]

References

[1] S. Saminathan, *Low energy beam transport line for the CANREB charge state breeder*, TRI-DN-15-06, Internal report, TRIUMF, Jan, 2015.

[2] T. Planche, *ARIEL 'Y30' Dipoles design note*, TRI-DN-13-15, Internal report, TRIUMF, July, 2013.

[3] R. Baartman, *End Effects of Beam Transport Elements*, Internal report, TRIUMF, July, 2001.

[4] Y. N. Rao, *Spec for EHBT Dipoles*, Internal report, TRIUMF, Nov., 2011.

[5] Y. N. Rao, *EHBT Magnet power supplies*, TRI-BN-11-ripples, Internal report, TRIUMF, Dec., 2011.

[6] F. Ames, *CANREB Nier-spectrometer*, Document-91140, Internal report, TRIUMF, July, 2013.

[7] G. Clark, Private communication, TRIUMF, Jan, 2015.