PERMANENT MAGNETS FOR THE TRANSFER LINES FROM THE MAIN INJECTOR TO THE 3 TeV VLHC INJECTOR

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September 28, 1997

Abstract

The parameters and preliminary designs for permanent magnet dipoles and quadrupoles suitable for use in the 150 GeV transfer lines from the Main Injector to the 3 TeV injector to the VLHC are described. The designs are based on the permanent magnets for the 8 GeV line and Recycler. The magnets use strontium ferrite permanent magnet material and temperature compensation alloy in the magnetic circuit. This is a companion to the note [1] by Bieniosek et. al. who describe the optics and geometry of the of the transport lines.

1 INTRODUCTION

The 150 GeV transfer lines from the Main Injector to the 3 TeV VLHC injector are essentially straight FODO channels 3km long. The beams are transported down at a 4% grade through the transfer line enclosures into the 3 TeV tunnel locate 450' underground. It is proposed to use permanent magnets based on the technology developed for the 8 GeV Line/Recycler for beam transport.

At either end of the line a 40mr (20 Tesla-m) vertical deflection is required. It is likely that additional horizontal bends will be required to match details of the final footprints of the tunnel. It is proposed to accomplish most of these bends with 0.6 Tesla permanent magnet dipoles. The remainder of the bends will be accomplished with vertically deflecting electromagnets (to pitch the beam downwards coming out of the Main Injector) and by the vertical kick from the injection Lambertson (in the 3 TeV tunnel).

The transfer line enclosure will also be used to transport the transmission line magnets railway-style down from the surface assembly building into the tunnel. An option under consideration is that most of one of the transport lines could be shared with the NUMI tunnel. More details are given in Ref. 1.

2 WHY PERMANENT MAGNETS?

The advantages of permanent magnets are that they avoid the cost and complexity of power supplies, power cabling, safety interlocks, LCW distribution piping, valves, and interconnections. Their main disadvantages are that the transfer line can be run over a smaller range of beam energy than a line built with electromagnets, and that certain types of beam line tuning experiments (e.g. tests of quad steering) are not possible. Since there seems to be no advantage to running the transport line at any energy different than the 150 GeV nominal top energy of the Main Injector, permanent magnets seem appropriate.

3 MAGNET APERTURE

The optical design for the transfer line adopts the *ansatz* that the 3 TeV ring and 150 GeV transfer lines have identical optics, i.e. 60-degree cells and a β-max of 200m. Thus the beam size in the transport line is identical to the circulating beam size at injection in the 3 TeV ring. Aperture requirements should in principle be identical. However we chose the minimum aperture of transport line magnets to be somewhat larger (2.5cm x 3cm vs. 2x2cm for the 3 TeV arc magnets). This seems reasonable in view of the fact that the beam transport enclosure passes through a variety of ground conditions on its way down to the bedrock of the 3 TeV machine.

A larger beam pipe than this may be desired for vacuum conductance reasons. We discuss designs below for 3½" beam pipe, 1¾" beam pipe, and 1" beam pipe.

As a side comment, it may be desirable to have explicit collimators to limit the beam size that might accidentally be introduced into the 3 TeV Injector and 150 GeV transfer line. This may be necessary since the aperture for circulating beam at flat top in the Main Injector is in excess of 1000π. Attractive places to scrape the beams are as they pass through the Main Injector abort (MI-40 line) and near the NUMI target station (MI60/NuMI line). This would ensure that no non-transportable beam halo (or badly mis-extracted beam) could be transmitted into the 3 TeV machine or transfer line.

4 QUADUPOLE PARAMETERS

The 60-degree cells for the 150 GeV transfer lines have a quad spacing of ~50m and require an integrated quad strength of 10 Tesla. Three design options were considered:

1) A stretched version of the 8 GeV/Recycler quadrupole[2] 3.5m in length and weighing about 1200lbs. This design permits a 3½" beam pipe to pass through.
2) By scaling down the previous design by a factor of two in all dimensions, the same integrated gradient is obtained and the magnet weights 1/8 as much. This permits a 1¾" beam pipe.

3) A "minimum aperture" design (Fig. 1) which barely exceeds the minimum aperture requirements discussed above. This design permits a 1" round beam pipe to pass through, or a larger elliptical pipe.

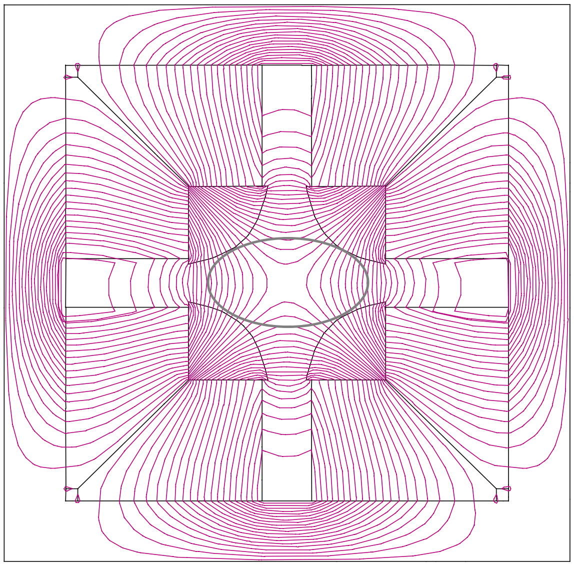


Fig. 1 – POISSON field map of the "Minimum Aperture" quadrupole design. Overall dimensions are 4.6" x 4.6" x 24" and the weight is approximately 90 lbs.

The three quadrupole design options are summarized in Table 1. At present I favor the intermediate option labeled "½ Scale Recycler". A fourth, attractive option which has not been developed is to scale down all dimensions of the Recycler design except the thickness of the ferrite brick (which would remain 1"). This would result in a magnet ~1.5m long which would fit around a 2" beam pipe.

	Stretched Recycler	½ Scale Recycler	Minimum Aperture
Beam Pipe Diameter	3.5"	1.75"	1"
Gradient	3 T/m	6 T/m	20 T/m
Magnetic Length	3.3m	1.7m	0.5m
Length Overall	140"	70"	24"
Height, Width	8"	4."	4.6"
Weight	1200 lbs.	150 lbs.	90 lbs.

Table 1 - Mechanical parameters for different quadrupole designs discussed in the text.

5 DIPOLE PARAMETERS

Bend dipoles with smaller apertures and somewhat stronger bend fields are straightforward extensions of the "Double-Double Dipole" permanent magnet design of the 8 GeV line[2]. In order to concentrate the flux from a larger volume of ferrite, the aspect ratio of the pole tip must be increased (see fig. 2). In principle this approach can be extended to obtain dipole fields >0.6T. However, it becomes very inefficient and subjects the ferrite near the magnet gap to large demagnetizing forces.

An option has been chosen in the dipole design is to place the temperature compensator alloy in the magnet gap, on either side of the beam pipe. This results in a more compact and efficient design but results in multipole defects that depend (weakly) on the operating temperature [3]. This is acceptable for a transfer line.

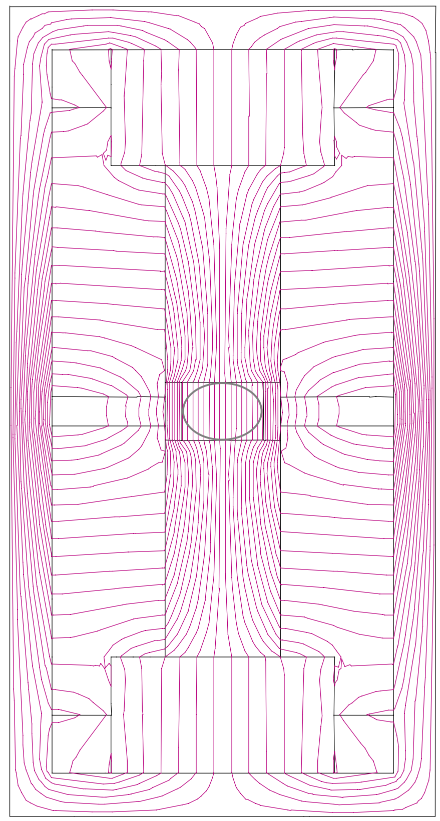


Fig. 2 – POISSON field map of the permanent magnet dipole for the 150 GeV transfer line to the 3 TeV injector.

Bend Field	0.6 Tesla
Magnet Gap	1" x 1.5"
Elliptical Beam Pipe	1.5" x 1"
Temperature Compensator	In Magnet Gap
Overall Dimensions	7.5" x 13.5"
Length	Up to 4m

Table 2 - Permanent Magnet Dipole parameters.

6 ROUGH COST ESTIMATE

The permanent magnets are very similar in design and production quantity to those for the Recycler and 8 GeV Line. Sixty-four Recycler quadrupoles were built at a cost about $3k each (dominated by labor cost). The two permanent magnet transfer lines require a total of 120 quads of comparable design, so a reasonable guess at their cost might be $360k. The dipole design is comparable to the "double-double" dipole design for the 8 GeV line, which cost $11k (dominated by M&S). Roughly 20 of these are required for both transfer lines, so that the total cost of permanent magnets for the line should be in the vicinity of $600k.

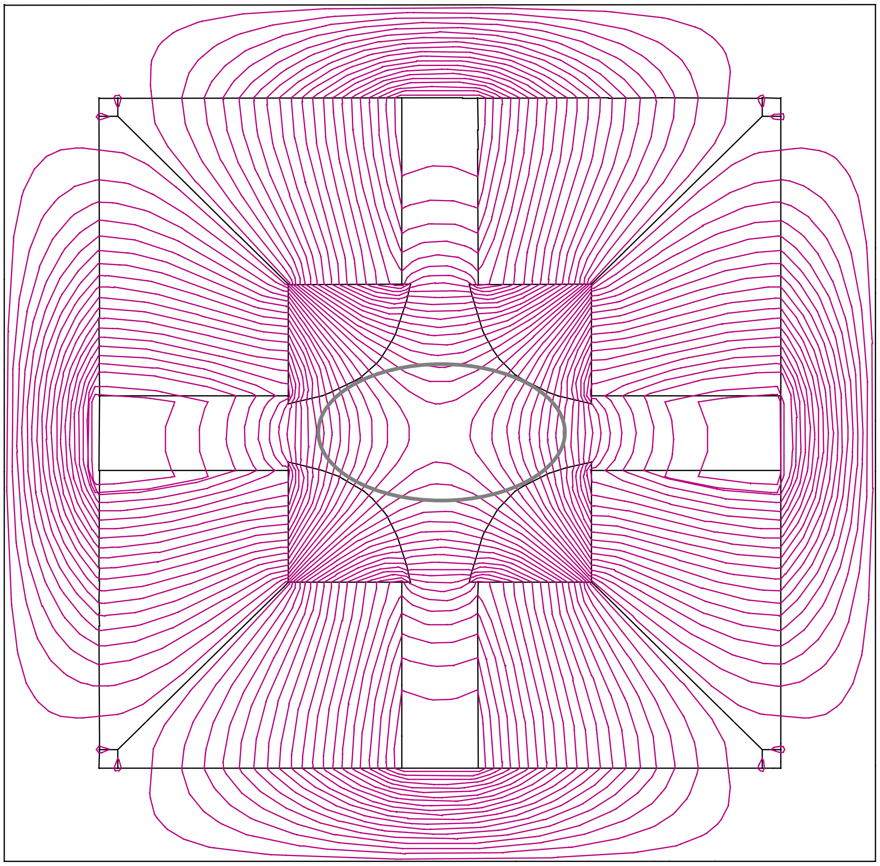
REFERENCES

[1] "Beam Transfer Lines for a VLHC", F. Bieniosek, N. Gelfand, D. E. Johnson, A. D. Russell, M.J. Yang, contribution to FNAL 1997 VLHC summer study.

[2] The 8 GeV line permanent magnets are described in the Fermilab Main Injector Technical Design Handbook.

[3] H. Glass, presentation on the temperature dependence of field multipoles in the Double-Double Dipole to the Main Injector Magnet Physics (MIMP) group, 1995.

VLHC Injector 150 GeV Transfer Line
Permanent Magnet Quad
(Minimum Aperture Design)



Gradient: 20 Tesla/m

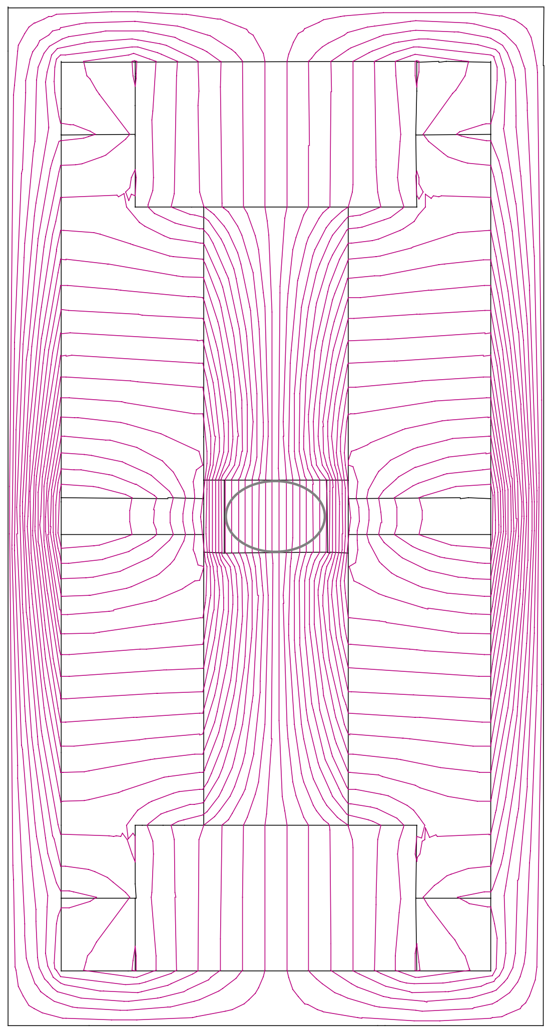
Magnetic Length: 0.5m

Pole Tip Diameter: 1”

Elliptical Beam Pipe: ~ 1.3” x 0.9”

Overall Dimensions 4.6” x 4.6” x 24”

VLHC Injector Transfer Line
Permanent Magnet Dipole



Bend Field: 0.6 Tesla
Magnet Gap: 1” x 1.5”
Elliptical Beam Pipe: 1.5” x 1”
Temperature Compensator in Gap
Overall Dimensions 7.5” x 13.5”
Length: up to 4m