SNS HEBT MOMENTUM SCRAPER, H+ RAY TRACE SIMULATION AND VACUUM CHAMBER DESIGN*

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Abstract

In the 1MW Spallation Neutron Source (SNS), the High-Energy Beam Transfer line (HEBT) connects the LINAC to the accumulator ring. A major requirement of the SNS complex is to have low uncontrolled beam loss (1nA/m), to allow hands on maintenance. The vacuum requirement for the HEBT is 5×10^{-8} Torr. Excessive H- stripping will occur above this pressure and increase losses in the machine. The HEBT is also equipped with three sets of beam halo scrapers, one for momentum and two for transverse collimation. The momentum scraper is located at a maximum dispersion point, between the 3rd dipole magnet (DD3) of HEBT and the 14th quadrupole (Q14) of the HEBT line. The momentum scraper uses movable foils that strip the H- beam that has momentum spread ($0.2\% < \delta p/p < 0.6\%$) into H+, and the H+ ions are then directed out of the HEBT beam line to a beam dump by the next bending magnet DD4 (4th dipole of HEBT). In order to ensure that the extracted H+ beam travels inside the extraction chamber to minimize the radiation in the beam dump station region, we performed H+ particle tracking to determine the outer boundaries and the angle of the Y-type vacuum chamber that will contain the H+ beam. The development and design of the special HEBT momentum scraper extraction and exit chamber, and the relevant H+ trajectories are presented in this paper.

1. INTRODUCTION

The Brookhaven National Laboratory is undertaking the design, construction and commissioning of the accumulator ring and the beam transport lines for the 1.0 GeV Spallation Neutron Source. A key feature of this accelerator is the requirement for low uncontrolled beam loss (1nA/m). To achieve such low beam loss, the beam must be prepared very carefully for injection into the accumulator. The HEBT not only matches the beam into the accumulator ring, but also determines the beam quality before injection. The 170m long SNS HEBT shown in Figure.1, has three sections [1]: Linac-Achromat Matching Section (LAMS), Achromat, and Achromat-Ring Matching Section (ARMS). Achromat provides momentum selection by cleaning up the beam energy halo at the point of maximum dispersion. A momentum scraper is located at that point to remove the longitudinal tails of

the beam before entering the ring. The number of losses expected in this collimator is much larger than in the transverse case due to the tighter longitudinal acceptance of the line and the ring. Also the incertitude about the energy jitter and momentum spread coming from the superconducting linac translate into a larger beam loss budget. This scraper is a movable stripping foil, which
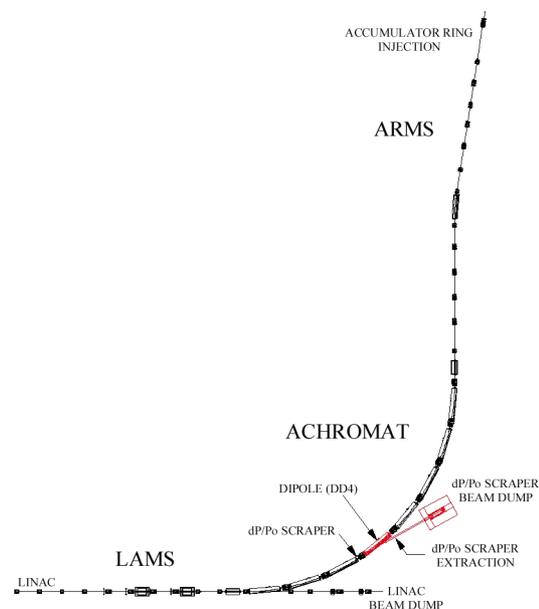

Figure 1. SNS HEBT and Momentum Scraper Location

strips H- into H+, followed by an off-line beam dump for the oppositely bent protons. Ions should only be detected at the beam dump, if the beam is not within energy spread and momentum specifications, indicating a malfunction. The machine will shutdown after one pulse is detected at the beam dump, as a means of machine protection. The adjustable foil shaves H- beam halo when the following condition is fulfilled: [2]

$$x_{cut} \le x = (\varepsilon_x \rangle \beta)^{1/2} \cdot \sin(\phi) + D \cdot \delta p/p_0$$

where x_{cut} is the foil horizontal position and D and β are the dispersion and beta function at the foil, ϕ is the betatron phase.

A schematic of this momentum stripping arrangement is shown in Figure 2. By H+ particle tracking, we obtain the information of H+ trajectories at different beam energies (1.0 GeV, 1.3 GeV), to develop the special

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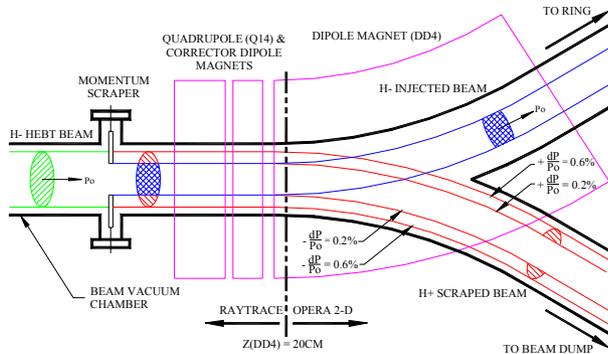design for the "Y"-type HEBT momentum scraper extraction chamber.

Figure 2. Schematic of SNS HEBT Momentum Scraper

2. THE RAY TRACE SIMULATION

In order to save the computation time, the simulation procedure was divided into two steps including a 2D model of the quadrupole (Q14) and dipole (DD4) magnets. The H^+ tracking was performed by using the RAYTRACE[3] code and OPERA-2D[4] code.

2.1 Particle tracking using RAYTRACE

A very general ion-optical computer code called RAYTRACE was used for H^+ particle tracking. RAYTRACE tracks one ray at a time through each element of the system using step by step numerical integration. If desired, a number of rays can be traced sequentially. The H^+ particles were assumed to be emitted from the striping foil (located ~35 cm downstream of DD3), passed through the quadrupole (Q14), and then into the dipole (DD4). We chose the ray exit position at 20cm beyond the entrance of DD4 as the start location for OPERA-2D simulation (section 2.2). In most of the elements, the particle typically moves through three distinct regions: the entrance fringing field, the 'uniform' field and the exit fringing field. RAYTRACE only concerns the fringing field in the longitudinal direction (z direction), unable to process the fringing field in the x or y direction (transverse plane). The beam parameters at the stripping foil location are shown in Table 1:

Beam Energy (T)	1.0 GeV	1.3 GeV
β_x, β_y	20.75, 5.27	22.14, 4.84
α_x, α_y	-2.08, 0.417	-2.11, 0.44
η_x, η_y	6.4, 0.0	6.52, 0.0
η'_x, η'_y	8.06, 0.0	7.87, 0.0

In RAYTRACE, each element has an input and an output coordinate system, the output coordinate system of one element coincides with the input coordinate system of the next element. Tables 2 and 3 show the RAYTRACE simulation results for various energies, including the initial coordinate at the stripping foil and the final coordinate 20cm beyond the entrance of DD4.

Table 2. Ray trace simulation result at 1.0GeV

1.0GeV	X_{in}(cm)	X'_{in}(mrad)	X_{out}(cm)	X'_{out}(mrad)
P_0	0	0	2.057	105.42
$+\Delta p/p$	4.24	5.32	-4.032	90.85
$-\Delta p/p$	-4.24	-5.32	8.175	120.09

Table 3. Ray trace simulation result at 1.3GeV

1.3GeV	X_{in}(cm)	X'_{in}(mrad)	X_{out}(cm)	X'_{out}(mrad)
P_0	0	0	2.057	105.42
$+\Delta p/p$	4.3	5.2	-4.051	91.19
$-\Delta p/p$	-4.3	-5.2	8.193	119.77

2.2 Particle tracking using OPERA-2D

Since the RAYTRACE code can't process the fringing field in the x-y transverse plane, we have to divide the simulation procedure into two steps. The first step, using RAYTRACE to get the particle trajectories from the stripping foil to a point 20 cm downstream of the DD4 entrance. The second step, using OPERA-2D to complete the particle trajectories to the beam dump.

OPERA-2D is a suite of programs for 2-dimensional electromagnetic field analysis. The programs use the finite element method (F.E.M.) to solve the partial differential equations (Poisson's equation, Helmholtz equation, etc.) that describe the behavior of fields. We developed a 2D model shown in Figure 3 for the DD4 dipole magnet. The TRACK command in post-processor,
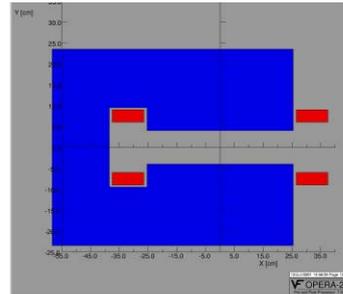

Figure 3. DD4's 2D model for OPERA-2D simulation

generates the particle trajectories from DD4 to the beam dump. The results are shown in Figures 4. The analysis indicates the maximum of Δ[dp_0%, dp+0.66%, dp-0.66%](1.3GeV-1.0GeV) is about ±0.02cm, the angle of the Y-type extraction vacuum chamber is 10.1698-10.1738.
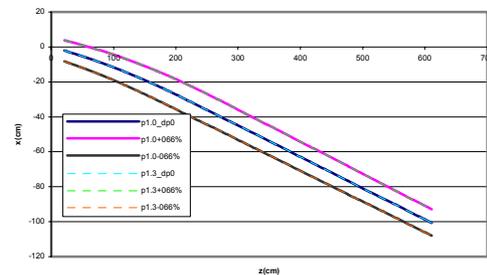

Figure 4. H^+ particle trajectories @1.0 and 1.3 GeV (X-axis corresponds to the center line of the dipole)

3. EXTRACTION CHAMBER DESIGN

Data from the horizontal $\Delta p/p_0 = \pm 0.2\%$ and $\pm 0.6\%$ ray trace simulations are transferred to the HEBT lattice, relative to the orthogonal axes of the HEBT dipole DD4. The resulting rays represent the minimum extraction chamber boundary and orientation. The rays bend out of the DD4 HEBT dipole downstream of the momentum scraper. Therefore, it is convenient to adapt the standard dipole chamber design to the design of the momentum scraper extraction chamber.

To create the momentum scraper dipole chamber, the standard HEBT dipole chamber geometry is modified to provide an unobstructed path for the extracted beam as well as the injected beam. Each of the nine HEBT dipole chambers must fit within the poles of the dipole magnets which are separated vertically by only 8 cm. The magnets are over 5 m in length and produce a bend angle and radius of 11.25º and 27.16 m respectively. The minimum clear horizontal aperture requirement for the injected beam is 16 cm. The chamber horizontal cross section is 19 cm, larger than the minimum requirement, principally to account for chamber and magnet manufacturing tolerances and limitations associated with the cost effective production of so few chambers. With normal manufacturing and installation tolerances applied, the clear aperture is >17 cm. The resulting standard chamber design, shown in Figure 6, is therefore quite long and flat, with a length approaching 6m, a width of 20 cm and a maximum height of 7.6 cm.

To accommodate both injected and extracted beams downstream of the momentum scraper in the DD4 dipole, a junction box takes the place of a portion of the standard dipole chamber. This junction box interfaces with the incoming beam at one end, and the injected beam and the
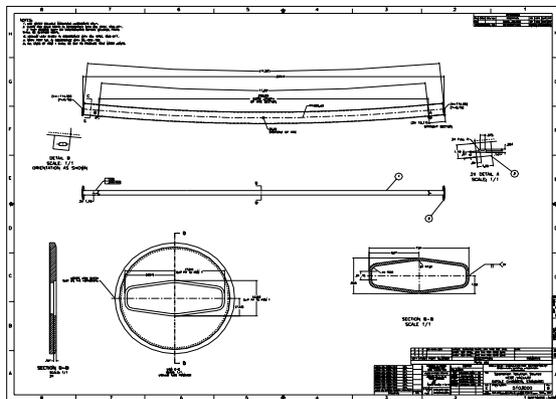

Figure 5. Standard HEBT Dipole Chamber

extracted beam, at the other end, thereby forming a "Y" type chamber. The wide acceptance required for the standard injected beam is also needed for the extraction chamber to insure that particles of $\Delta p/p_0$ up to $\pm 0.6\%$ arrive at the beam dump. The $\Delta p/p_0 = \pm 0.6\%$ corresponds to $\pm 10\sigma$ for the population distribution. In this case, the custom tube used for the injected beam is also suitable for the extracted beam. This design requires a substantial amount of welding. To preserve magnetic field quality, 316L material is required for all parts of the chamber, and subassemblies with longitudinal welds are annealed to produce a magnetic permeability of ≤ 1.1. The resulting momentum scraper extraction chamber design is shown in Figure 6.
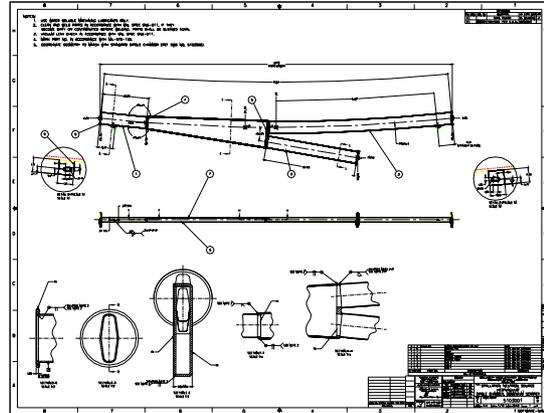

Figure 6. Momentum Scraper HEBT Dipole Chamber

4. SUMMARY

Using the RAYTRACE and OPERA-2D, we have simulated H^+ particle trajectories from the stripping foil to the beam dump. Based on the simulation results, the special HEBT momentum scraper extraction and exit chamber has been designed. The chamber meets the requirement of the outer boundaries and the angle of H^+ exit ray traces and maintains the beam loss in the extraction beam pipe below the required 1nA/m.

5. REFERENCES

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[4] VectorFields Inc., OPERA-2D Reference Manual