EFFECT OF MAGNETIC FIELDS ON THE DOSE ESTIMATES DUE TO BEAM HALO LOSS IN THE RING COLLIMATION STRAIGHT OF THE SNS*

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Abstract

The collimation straight section of the SNS ring consists of three collimators with magnets (doublets and correctors) between them. It has been determined [1] that a large fraction of the particle halo loss occurs at the primary and secondary collimators. The dose to ring components in this location has been studied in the past [2]. In this revised dose estimate the effect of including the magnetic fields associated with the doublet located between the collimators will be made.

The dose estimates are made using the MCNPX multi-particle Monte Carlo code [3], with an appropriate modification which allows tracking charged particles through magnetic fields [4]. The magnetic field is pre-generated by the COSY INFINITY code [5]. The pre-generated data is in the form of a map, which is assigned to each magnetic cell in the MCNPX calculation. The dose to selected components, and the sensitivity of its magnitude to the presence of the magnetic field will be evaluated.

1 INTRODUCTION

In this paper an estimate of the dose to quadru-pole and corrector windings in the collimation straight of the ring will be made. In all the above estimates the machine is assumed to operate at an average power of 1.5 MW, with a proton energy of 1 GeV, and a loss of 0.001. In the case of the dose estimates it was assumed that the loss occurs at the four scrapers in the primary collimator. If the loss magnitude is different at the scrapers the dose to components will change in proportion. In these estimates a section of the collimation straight will be simulated, including the primary scraper/collimator, the first secondary collimator, and a doublet (consisting of two quadru-poles of unequal length) located between the collimators. The tunnel walls are also included in the simulation, since they can be a source of scattered radiation.

2 METHODS AND MODELING

The above estimates of dose are based on the MCNP [6] family of codes. In the case of the dose estimate the MCNPX [3] code was used. This code uses the combinatorial representation of geometry, in the same way all previous MCNP based codes have used it, and the geometry descriptions are inter-changeable among all codes. However, MCNPX has a high energy transport section available, which allows the same physical phenomena as the LAHET code [7]. The primary proton (1 GeV), and all the resulting secondary particles can be followed, edited and tallied in any desirable manner over the entire energy range of interest.

In order to include a magnetic field in the MCNPX analysis an appropriately modified version of the code [3,4], which allows tracking of charged particles through magnetic fields in designated vacuum volumes was used. These volumes are the vacuum chamber enclosed by the quadru-pole magnets making up the doublet between the collimators. The magnetic fields have to be pre-generated and entered into the code in tabular form. The magnetic field tables are generated in the appropriate format by the COSY INFINITY code [5], and have to be generated prior to carrying out the MCNPX calculation. It is possible to orient the axis of the quadru-pole field at an arbitrary angle with respect to a reference direction. It is thus possible to model the most important aspects of the doublet field. The fringe fields at the entrance and exit to the magnet are not included in this analysis.

The actual layout of the lattice in the collimation straight of the ring is shown in Fig. 1. From the figure it is seen that the straignt section is approximately 12 m in length, with two collimators, a doublet, a quadru-pole at the beginning, and a corrector magnet. The distance between the quadru-poles and the two collimators at the beginning is approximately 1.5 m, and the distance from the primary scraper/collimator to the corrector magnet is approximately 0.5 m. The primary scraper/collimator consists of a 0.55 cm thick platinum scraper which protrudes into the halo, and perturbs the beam orbit sufficiently that the particles are deflected into one of the secondary collimators.

The four scrapers are placed at 140 Bmm/mrad, while all the collimator tubes have an aperture of 300 Bmm/mrad. The inlet to the primary collimator is consistent with the vacuum chamber aperture at that location in the ring (~ 20 cm in diameter).

The two quadru-poles making up the doublet are 0.7 m and 0.55 m in length, and have magnetic field strengths of 0.5 T and 0.55 T respectively. The distance between the magnets was assumed to be 0.25 m.

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3 EFFECT OF MAGNET FIELD ON PARTICLE FLUXES INSIDE VACUUM CHAMBER

In order to determine the effect of the magnetic field on the scattered proton halo beam, and the subsequent generation of secondary particles (neutrons and gamma-rays), eight azimuthal volumes were created in the vacuum chamber at the locations of interest. The location of the volumes are indicated on Fig. 1, and are at the exit of the primary collimator, between the quadru-poles making up the doublet, and at the entrance to the secondary collimator. Three sets of results are shown on Table 1; those without the magnetic fields present (traditional analysis method), those with the scrapers removed (to validate the algorithm used to represent the magnetic fields), and those which include both the scrapers and the magnetic fields. It is seen that at the first location (exit of primary collimator) the distributions which include the scrapers are essentially the same, since the protons have not passed through a magnetic field at this point, and the distribution without the scrapers present is azimuthally isotropic. However, at the next location the distributions start diverging, while the protons without a magnetic field but with a scraper still have essentially the same distribution the protons that have passed through the first magnet are concentrated primarily in four cells. The distribution without the scraper is symmetric, with the bulk of the particle concentrated between 45^0 - 135^0 and 225^0 - 315^0. The distribution which includes both the scraper and the magnetic field has a similar shape, but it is not as symmetric, reflecting the presence of the scraper which changed both the momentum and angular distribution of the halo. Finally, at the last location considered (entrance to secondary collimator), the proton flux distribution corresponding to the calculation without a magnetic field and with a scraper is still largely unchanged from the first distribution. However, the distributions including a magnetic field shows a significant concentration of the proton halo in four azimuthal cells. In the case with no scraper present the distribution is concentrated in the directions mentioned above; but for the case with a scraper present the concentration is largely between 135^0 - 225^0 and shows an increasing effect of the scraper.

Table 1. Azimuthal proton flux as a function of position (with and without magnetic fields in quadru-poles and scrapers).

Azimuthal Angle bin	Proton flux (p^+/cm^2-s/primary) W/O field+Sc*	W/O Sc+field	With field and SC
	Exit from Primary Collimator		
0 - 45	2.9395-3**	3.9115-3	2.9376-3
45 – 90	2.8336-3	3.8707-3	2.8366-3
90 – 135	3.5224-3	3.9901-3	3.5188-3
135 – 180	4.2529-3	3.9511-3	4.2535-3
180 – 225	4.1583-3	3.8700-3	4.1578-3
225 - 270	4.2639-3	3.593-3	4.2658-3
270 – 315	3.5580-3	3.9222-3	3.5578-3
315 – 360	2.8358-3	3.9631-3	2.8370-3
	Between Quadru-pole Magnets		
0 – 45	2.6021-3	6.1008-4	1.40-3
45 – 90	2.5624-3	4.9126-3	3.6862-3
90 - 135	3.4697-3	4.8180-3	5.5059-3
135 – 180	4.3930-3	6.1249-4	2.3291-3
180 – 225	4.3641-3	6.0940-4	2.3159-3
225 – 270	4.4078-3	4.8769-3	6.4029-3
270 – 315	3.4811-3	4.8062-3	4.5423-3
315 - 360	2.5687-3	5.9624-4	1.3975-3
	Entrance to Secondary Collimator		
0 – 45	2.4906-3	1.0975-3	1.0691-3
45 – 90	2.4648-3	2.3698-3	2.4333-3
90 – 135	3.4008-3	2.3563-3	2.3495-3
135 – 180	4.3552-3	1.0441-3	3.7849-3
180 – 225	4.3345-3	1.0811-3	3.7927-3
225 – 270	4.3658-3	2.3546-3	2.3291-3
270 – 315	3.4151-3	2.3104-3	2.4185-3
315 – 360	2.4648-3	1.0532-3	1.0657-3

*Sc = Scraper

** 2.9395-3 = 2.9395×10^{-3}

The production of secondary particles increases with the inclusion of the magnetic fields. This is primarily due to the deflection of the proton trajectories to intercept a magnet component and thus act a source of secondary particles. In a more traditional estimate of dose to accelerator components the magnetic deflection of scattered halo particles would not be accounted for, and thus would result in an under-estimate of the total dose. The azimuthal distribution in all cases is essentially uniform, since the secondary particle production is largely isotropic.

4 MAGNET DOSE ESTIMATES

Dose estimates were carried out for the section of the magnet windings protruding from the magnet frame. Thus there are four cells on each side of a quadru-pole magnet. The averaged estimated doses for the various magnets are shown on Table 2, with and without the magnetic fields present. Face number one of the first quadru-pole experiences approximately the same dose with or without the magnetic field present. However, for all subsequent faces the doses estimated with the magnetic fields present are significantly higher, than without the field. The highest dose is seen to be approximately 1500 mrad/s, experienced by the second quadru-pole. This dose is higher than the estimate made earlier [2], which did not include the effect of a magnetic field but was made for an operating power of 2 MW rather than the revised value of 1.5 MW assumed in this analysis.

The life expectance of kapton (proposed insulation for the magnet windings) in a radiation field is between $5\text{x}10^8$ rad - 10^9 rad, thus at the highest dose rate the magnet insulation should last approximately 10^5 hrs - $2x10^5$ hrs. If it assumed that the machine will operate for three quarters of a year it should be expected that the first doublet will have to be changed at least once in the machine lifetime - assuming a thirty year life.

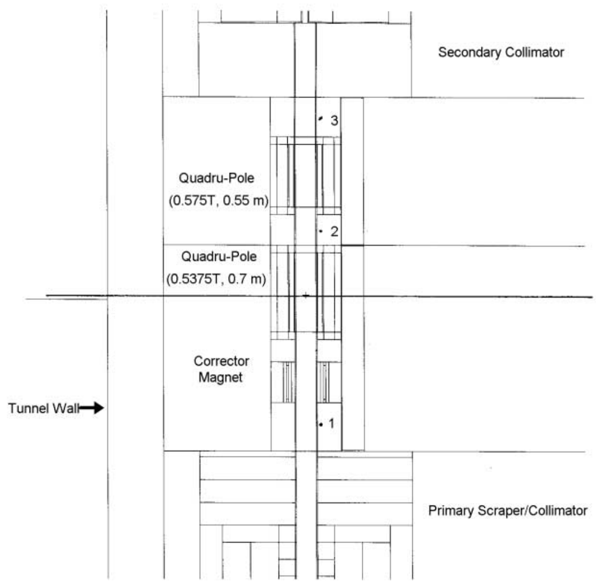

Figure 1: Lattice layout showing location of azimuthal volumes

Table 2. Dose to quadru - pole magnet windings without and with magnetic fields (mrad/s)

Magnet/ Face number	Without field	With field
First quadru-pole/face #1	277	309
First quadru-pole/face #2	196	533
Second quadru-pole/face #	1577	711
Second quadru-pole/face #	2328	1591

5 CONCLUSIONS

The following conclusions can be drawn from this study:

1) The results reported in this study are a strong function of the assumptions regarding loss fraction, magnetic field strength, and average power,
2) In this study it was assumed that the scrapers intercept 0.001 of the beam, and the accelerator operated at an average power of 1.5 MW. The effect of any variation from these assumptions can be obtained by scaling (within limits),
3) The presence of a magnetic field interacts with the scattered halo particles to enhance the dose on the accelerator components in this section,
4) Future dose estimates of beam loss in the vicinity of a magnetic or electric field should include the effects of those fields on the scattered halo particles. Including these fields might increase (as in this example) or decrease the dose, but accurate estimates need to include electro-magnetic field effects.

6 REFERENCES

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