RADIATION DAMAGE TO THE ELEMENTS OF THE SIS300 DIPOLE*

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Abstract

Radiation damage to various elements of the cosθ-type dipoles of the SIS300 synchrotron of the FAIR Project was calculated. Among the elements under consideration were the superconducting cable, insulating materials, and high-current by-pass protection diodes. The Monte-Carlo particle transport codes MARS and SHIELD were used to simulate propagation of the lost ions and protons, together with the products of nuclear interactions in the material of the elements. It was found that the lifetime of the protection diodes under irradiation is a more restrictive limit for the tolerable level of beam losses than the occurrence of magnet quenches.

INTRODUCTION

The SIS300 superconducting synchrotron as a part of the FAIR project [1], will operate with U ions in the following regimes:

- High-energy "CBM regime": acceleration up to energy $E \approx 37$ GeV/u, intensity $N \approx 10^{10}$ particles, cycling time ~ 20 s, slow extraction with duty factor ~ 50%;
- "Stretcher regime": no acceleration, $E \approx 1$ GeV/u, intensity $N \approx 10^{12}$ particles, cycling time ~ 1 s, slow extraction with duty factor ~ 100%.

In order to estimate the radiation damage in the construction elements of the dipole, most critical from the radiation hardness point of view, numerical studies provided:

- on the quench danger: instantaneous energy deposition into the superconducting (s.c.) wires,
- on the lifetime of organic materials: accumulated energy deposition in the insulation,
- on the life time of the protection diodes: accumulated neutron flux and energy deposition in the high current by-pass semiconducting diodes.

This work is a continuation of the activity of modelling the energy deposition in the s.c. dipoles of the FAIR SIS100 & 300 synchrotrons, started in [2].

SIMULATION MODEL

The Monte-Carlo transport code SHIELD [3] was used to simulate the propagation of lost beam particles, together with products of nuclear interaction, through the construction elements of the SIS300 dipole [4].

Geometry and Material Composition

The simulation model consists of a cylindrical cryostat, with the dipole, diodes and the yoke located inside, Fig.1.

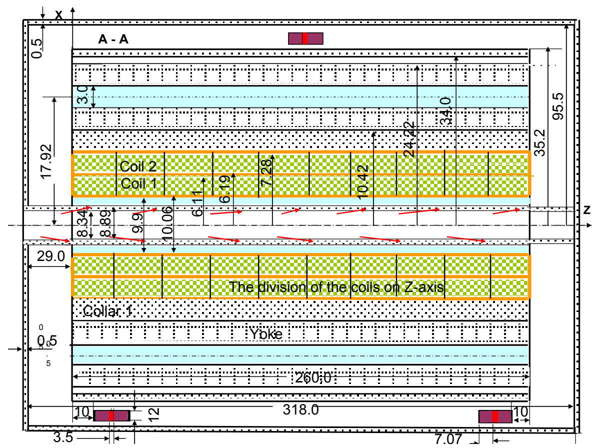

Figure 1: General view of the simulation model.

The three protection diodes are placed in different locations along the yoke, in order to probe the neutron flux and determine the safest position for the diodes inside the cryostat.

The cross section of the simulation model for the dipole itself, along with the dimensions of the construction elements, is given more detailed in Fig. 2.

The material composition of the construction elements is given in Table 1.

Irradiation Model

We have chosen the following irradiation patterns to simulate different regimes:

- In the CBM regime, fully stripped $^{238}U^{92+}$ ions will be lost mainly during the slow extraction at the top energy. Thus in the simulation model, projectiles with $E = 37$ GeV/u irradiate the inner surface of the vacuum chamber under the grazing incidence of 1 mrad. The incidence points are distributed uniformly over the length of the vacuum chamber, as well as over the transverse azimuthal angle $0 \leq \varphi < 2\pi$.
- In the stretcher regime, partially stripped $^{238}U^{28+}$ ions will be lost mainly due to the charge exchange with the molecules of the residual gas: thus the energy was chosen to be $E = 1$ GeV/u, with an incidence angle of 17 mrad and the incidence points were distributed uniformly longitudinally and transversally only over half of the inner surface of the vacuum chamber (angle $0 \leq \varphi < \pi$).

The high-energy CBM regime has also been simulated with the MASR [5] code, substituting the U ions with 238 protons. Both codes gave fairly good agreement with each

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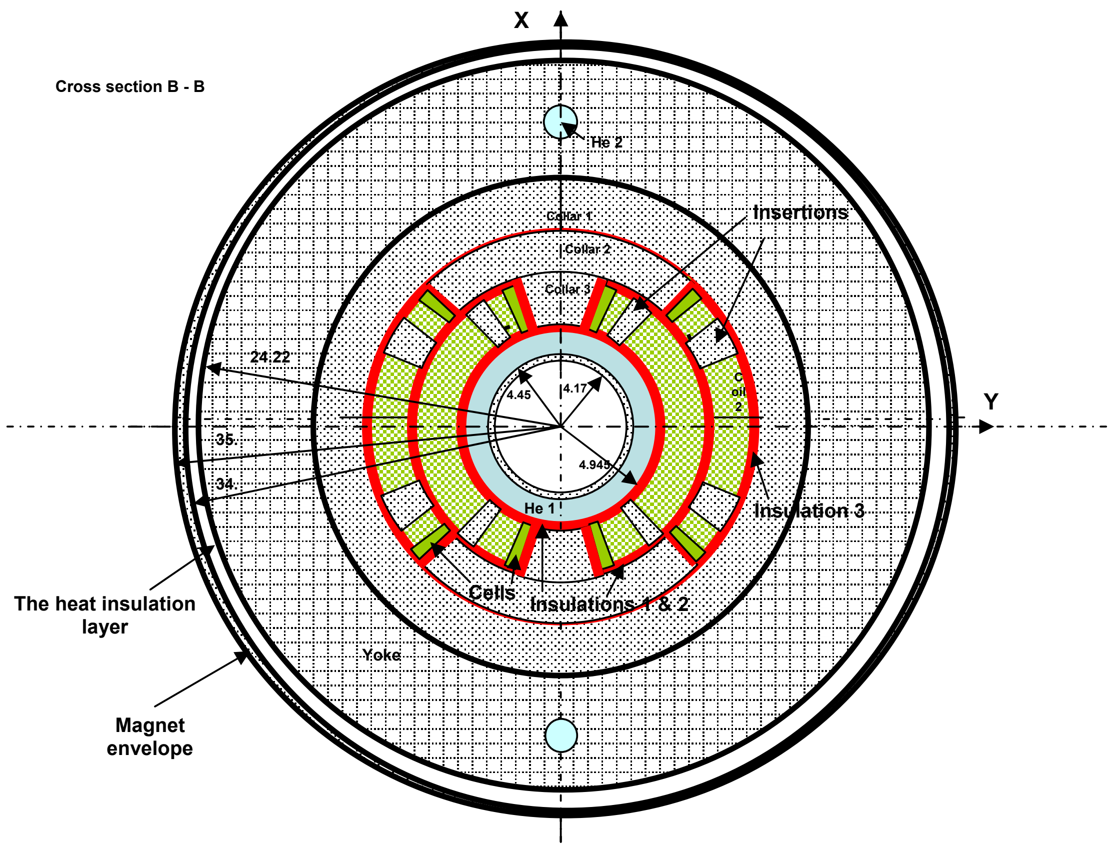

Figure 2: Simulation model for the SIS300 dipole in cross section.

other. Furthermore, we refer to the results obtained by the SHIELD code only, unless it is specified differently.

RESULTS OF SIMULATION

Energy deposition and neutron flux were present in all construction elements listed in Table 2. In Table 3 we present the most important values only, namely: the highest values of energy deposition in the s.c. wires and in the insulations, for different regimes and corresponding neutron flux in the diodes.

We compared the energy deposition and neutron flux in the protections diodes, calculated with the MARS code using protons for projectiles, and SHIELD, using U ions. The MARS code gave $1.6\cdot10^{-14}$ Gy and $1.4\cdot10^{-3}$ n/cm^2 per lost proton respectively. This corresponds to $3.8\cdot10^{-12}$ Gy and 0.33 n/cm^2 per 238 protons, which is consistent with the SHIELD numbers: $2.7\cdot10^{-12}$ Gy and 0.29 n/cm^2 per lost U ion.

Another important result from the SHIELD code was the spectra of different fragments in the s.c. wires. No fragments heavier than ^{4}Be were found in the s.c. wires in the CBM regime. The flux of ^{4}Be was found to be about $5\cdot10^8$ cm^{-2} in 10 years. This number will give an indication of heavy ion flux value one should use in future irradiation experiments, studying the s.c. material radiation hardness under heavy ion bombardment.

ESTIMATES FOR TOLERABLE BEAM LOSS LEVEL

The adiabatic quench energy deposition limit for the SIS 300 dipole [6] has been calculated as 0.6 mJ/g. For the radiation hardness of the insulation material we assume 10^6 Gy, as a typical value for irradiation with γ quanta or slow neutrons, in 10 years [7] and for the limiting neutron flux in the protecting diodes we assume 10^{14} n/cm^2 in 10 years [8].

The resulting estimates are given in Table 3, where it was taken into account that the SIS300 operates 70% of the year in the CBM regime and 20% in the stretcher regime. One can see that the most restrictive limit ($3\cdot10^7$ lost ions per magnet per cycle for the CBM and $3\cdot10^8$ for the stretcher regime) comes from the lifetime of the insulators and protection diodes.

If we further assume that the slow extraction losses mostly happen in one superperiod of the SIS300 with length L = 180 m, then the allowed loss level in terms of total beam intensity would be ~20% of slow extraction losses for the CBM regime and ~2% of charge-exchange losses in the stretcher regime.

Table 1: Material Composition of the Construction Elements of the SIS300 Dipole

Name of the Construction Element	Composition	Partial Density, g/cm^3	Total Density, g/cm^3
Vacuum chamber, insertions in the coils, collar, the magnet envelope, cryostat skull	Stainless st.: Cr - 20% Ni - 16% Mn – 6% C - 0.03% N – 0.25% Fe – 57.7%	 1.465 1.323 0.464 0.001 0.005 4.542	7.8
He I (around the vacuum chamber)	He – 100%		0.1359
He II (in channels)	He – 100%		0.066
Yoke	Fe – 98.5% Si – 1.46% C – 0.04%	7.742 0.057 0.001	7.8
Insulation 1	Kapton: C – 55 at.% H - 26 at.% N - 7 at.% O - 12 at.%	 0.94672 0.03729 0.14057 0.27541	1.4
Insulation 2,3	Glassfiber: Si – 25% O – 46% Al – 12% Ca – 13% Mg – 1% B – 3%	 0.475 0.874 0.228 0.247 0.019 0.057	1.9
S.c.wires of coil 1 and 2	Cu– 55.53% Ti – 20.12% Nb– 20.12% Si – 1.05% O – 1.95% Al – 0.51% Ca – 0.55% Mg – 0.04% B – 0.13%	3.053 1.106 1.106 0.058 0.107 0.028 0.030 0.002 0.007	5.498
Diodes 1,2,3	Si – 100%	3.020	3.020
Electrodes of the diodes	Cu – 100%	8.933	8.933

Table 2: Energy Deposition and Neutron Flux in Critical Construction Elements for Different Regimes

Construction Element	CBM	Stretcher
Coil 1, mJ/g per ion	$1.0 \cdot 10^{-9}$	$1.5 \cdot 10^{-11}$
Insulation 1, Gy per ion	$2.9 \cdot 10^{-9}$	$3.2 \cdot 10^{-11}$
Diode 3, n/cm^2 per ion	0.29	0.006

Table 3: Tolerable Beam Loss Level in the SIS300 for Different Regimes in Units of Ions/(Magnet Cycle)

Construction Element	CBM	Stretcher
Quench limit	$\sim 6 \cdot 10^{8}$	$\sim 4 \cdot 10^{10}$
Insulation lifetime limit	$\sim 3 \cdot 10^{7}$	$\sim 5 \cdot 10^{8}$
Diode lifetime limit	$\sim 3 \cdot 10^{7}$	$\sim 3 \cdot 10^{8}$

CONCLUSION

The most limiting requirement for the tolerable beam loss level in the SIS300 comes from the lifetime of materials with low radiation hardness (organic insulators and protection diodes). The estimated tolerable slow extraction loss level for the stretcher operating regime is about 2% of total beam intensity. From present machine experience one knows that the typical slow extraction loss level value is about 10%. Thus, special care should be taken in the synchrotron to protect the superconducting dipoles in the slow extraction area from the impact of beam loss.

The tolerable loss limit requirements from the material activation (to insure the "hands-on" maintenance) are still under theoretical and experimental investigation.

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