RADIATION DAMAGE STUDIES FOR THE SLOW EXTRACTION FROM SIS100*

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Abstract

During the slow extraction from SIS100 synchrotron 5% of the beam will hit the wires of the electrostatic septum and will be lost. These losses produce very high radiation damage to the superconducting quadrupole doublet situated downstream of the extraction point [1]. These beam losses were simulated with the help of the Fluka [2], [3] code for U^{28+} and Ne^{5+} beams. Non-zero cross-section and non-zero angular divergence were assumed for the lost beam, allowing distributed modeling of the slow extraction losses. The radiation damage to different layers of the superconducting (s.c.) quadrupole cables was calculated. The lifetime of the s.c. cables of the quadrupoles was found to be too short. Thus, alternative quadrupole designs with higher radiation tolerances were investigated: with stainless steel shielding of the s.c. cables and with a gap in the mid-plane between the s.c. cables.

SIMULATED PART OF THE SLOW EXTRACTION

The modeled part of the slow extraction area consisted of the electrostatic septum, two extraction kickers next to each other (these were modeled as a single unit) and the quadrupole doublet consisting of two similar quadrupoles and a collimator. A general view of the model is presented in Fig.1.

Planned intensity for U^{28+} and Ne^{5+} beams is 3×10^{11} ion/s. Thus, the expected beam losses due to the interaction of ions with the electrostatic septum wires is 1.5×10^{10} ions/s. Extraction energies for U^{28+} and Ne^{5+} are 2.7 GeV/u and 6.5 GeV/u. Beam divergence before the electrostatic septum is 0.1 mrad.

Schematic view of the electrostatic septum lay-out is given in Fig.2. Each wire has diameter of 0.1 mm and the distance between the wires is 4 mm. Wires are placed in a straight line tilted 1.3 mrad towards the beam axis. The distance between the first wire and the beam axis is 4 cm. Fig.3 presents simulation data of energy deposition in the first 50 wires of the electrostatic septum.

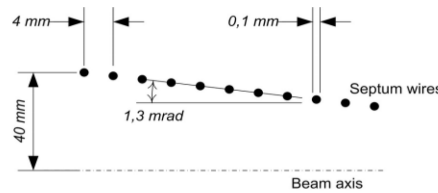

Figure 2: Electrostatic septum wires.

Profile of losses due to interaction with the septum wires has been obtained. Fig.4 shows the fraction of ions hitting the wires of the septum in dependence on the distance along the beam axis. For U^{28+} 3% of losses occur in kickers, 29% in the quadrupole 1, 34% in the collimator, 14% in quadrupole 2 and 20% of the lost ions are still inside the vacuum chamber after the quadrupole doublet. For Ne^{5+} the respective values are 1%-5%-38%-1%-55%. In both cases the most radiation-stressed elements are the quadrupoles and the collimator.

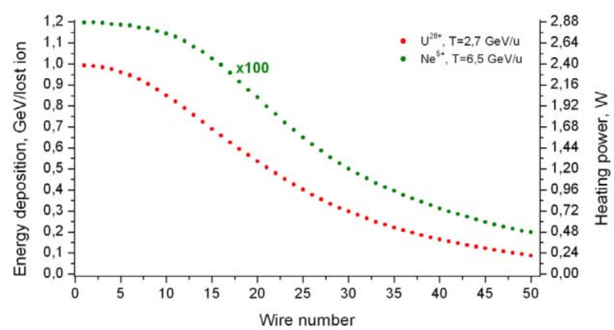

Figure 3: Energy deposition in the el. septum wires. Note that the Ne curve was increased by a factor of 100.

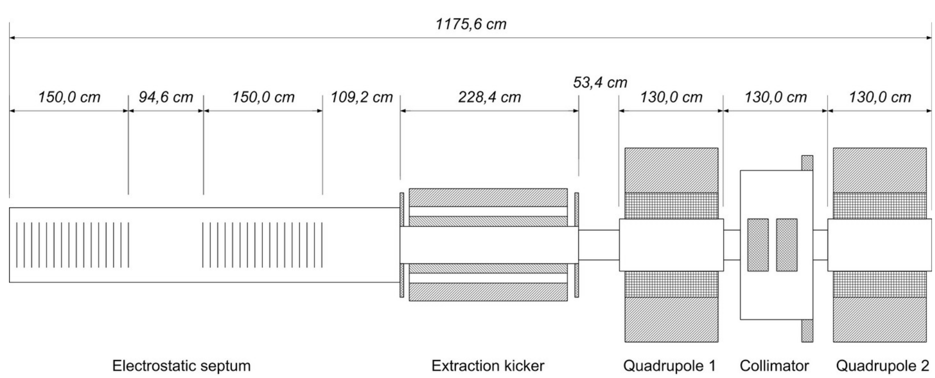

Figure 1: Modeled area of the slow extraction.

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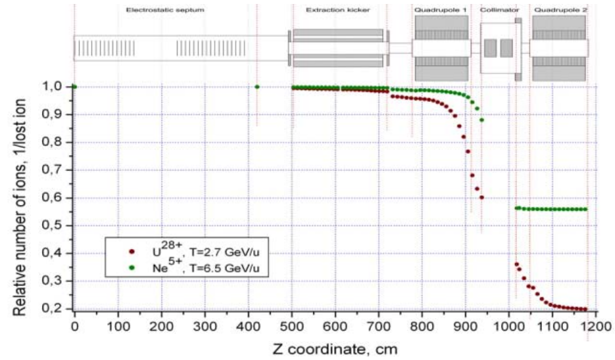

Figure 4: Fraction of losses along the beamline vacuum chamber.

ENERGY DEPOSITION IN S.C. CABLES OF THE QUADRUPOLES

The s.c cable of the quadrupole consists of 5 layers: liquid helium, cooling tube, s.c. wire, reinforcing bandage and the Kapton insulator Fig.5. Under interaction with the lost ions Kapton loses its dielectric properties, also there is a possibility of quench in the s.c. wire. Therefore Kapton and s.c. wire were studied in detail in the simulation.

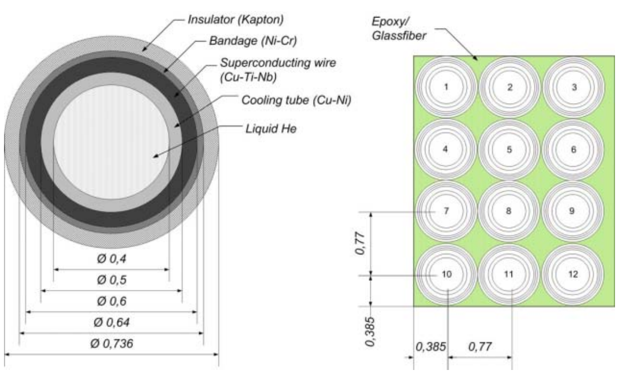

Figure 5: S.c. cable of the quadrupole and the wire assembly.

It was found that the s.c. cables receive too high irradiation dose. Assuming the lifetime dose of Kapton at 100 MGy, the Kapton lifetime is only 120 hours for continuous U beam operation at maximum intensity. For this reason two alternative quadrupole designs were investigated: with stainless steel shielding of the s.c. cables and with a gap in a mid-plane between the cables (see Fig.6).

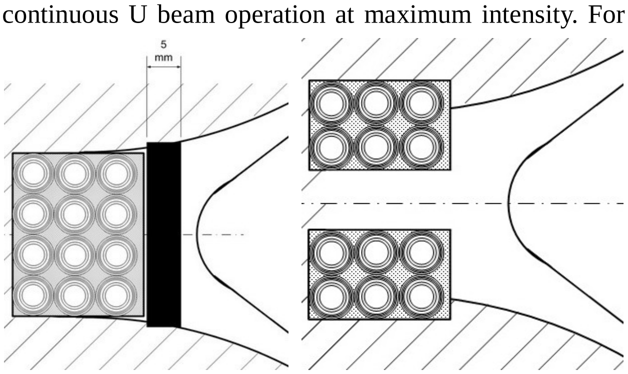

Figure 6: Alternative design of the s.c. cables: with a steel shielding (left) and with a mid-plane gap (right).

Uranium beam (U^{28+})

Comparison of profiles of longitudinal energy deposition in Kapton and s.c. wire of the most affected cable is presented in Fig.7 and Fig.8.

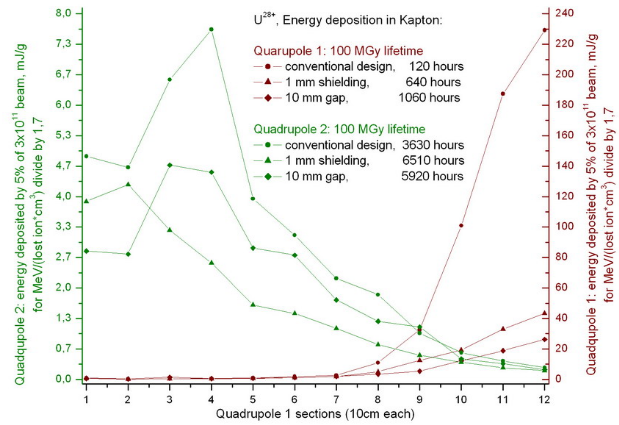

Figure 7: Energy deposition in Kapton layer, U^{28+}.

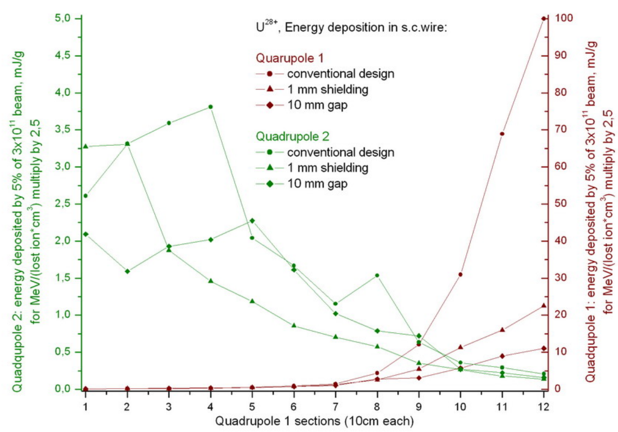

Figure 8: Energy deposition in s.c. wire, U^{28+}.

1 mm of steel shielding of the s.c. cables produces a good result increasing the Kapton lifetime by a factor of 5. 5 mm shielding allow to increase the lifetime by a factor of 10 [1]. A 10-mm gap in the mid-plane of cables increases the insulator lifetime by a factor of 8. A 20 mm gap allows increasing the lifetime by a factor of 45. Losses in quadrupole 2 are substantially lower and various cable designs do not produce a big difference in the insulator lifetime.

The quench limit in the s.c. wires is 1,65 mJ/g in case of “instant” energy deposition and at least more than 165 mJ/(g*s) for slow energy deposition [4]. There is a considerable quench danger for the conventional quadrupole design. For the designs with the shield and with the gap there should not be any danger of quenching.

Neon beam (Ne^{5+})

A comparison of the energy deposition profiles in Kapton and s.c. wire was also performed for the neon beam. The results are presented in Fig.9 and 10. Energy losses in quadrupoles for neon are sufficiently lower and there is no big difference in the energy deposition profiles between various cable designs for either quadrupole 1 nor 2. Also, there is no danger of quenches in the s.c. wires.

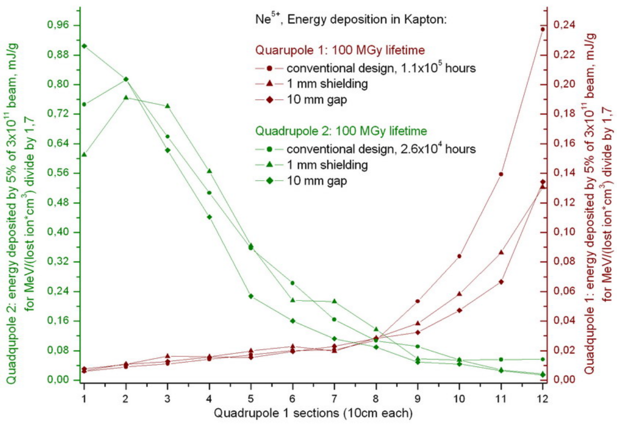

Figure 9: Energy deposition in Kapton layer, Ne^{5+}.

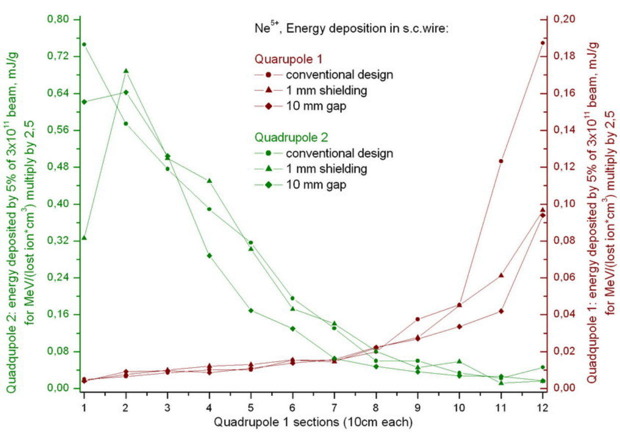

Figure 10: Energy deposition in the s.c. wire, Ne^{5+}.

RESIDUAL DOSE RATE

3 months of continuous operation followed by 1 month of cooling was considered for SIS100 operation in order to estimate the activation danger. It was assumed that 30% of time is dedicated to U^{28+} slow extraction. The residual dose rate in the slow extraction area was calculated for 1 year of such operation and 1 year of cooling after the operation. Fig.11 shows residual dose rate map in the slow extraction after 1 year of operation. The time evolution of the maximum dose rate in the modeled area is shown on Fig.12 along with the maximum dose rate near the cryostat wall of the quadrupole doublet and the maximum dose rate at the wires of the septum (both are multiplied by factor a 10).

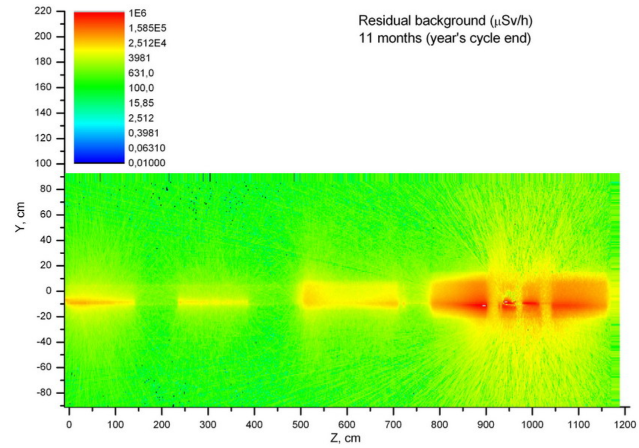

Figure 11: Residual dose rate after 1 year of operation.

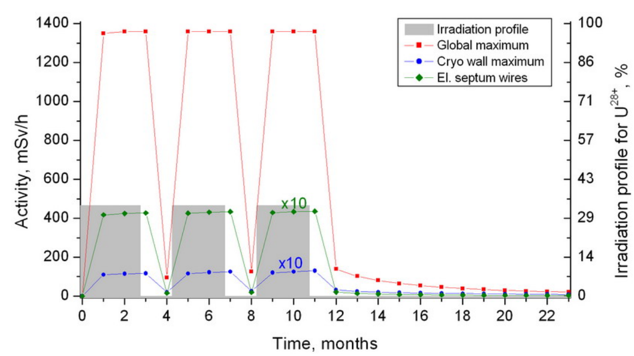

Figure 12: Time dependence of maximum dose rates.

CONCLUSION

Simulations have shown that the beam losses in the slow extraction area produce severe radiation conditions for the quadrupole doublet, decreasing the s.c. cable lifetime. In order to increase the lifetime the alternative quadrupole designs were investigated and simulations have shown promising results. It also found that the residual dose rate in the slow extraction area due to the slow extraction beam losses is too high for the current design.

REFERENCES

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