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PROTECTION OF SUPERCONDUCTING MAGNETS AGAINST IRRADIATION

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Abstract This work generalizes the experience in numeric simulation and on the study of protection of the superconducting magnets of the UNK against irradiation. The proposed measures are: application of the beam abort in the case of a radiation danger, loss localization in the special sections of the accelerator structure and the use of the beam injection interlock system. Using a system of local orbit distortions and movable collimators one may protect magnets against irradiation. This approach decreases the radiation heating of the superconducting coils below the ΔT=0.2 K during fast losses of $\sim$1% of the total circulating beam intensity.

1. INTRODUCTION

A fraction of the beam lost in the UNK at various stages of the acceleration cycle may cause the superconducting magnets to operate in ionizing radiation fields. The most stringent situation related to the radiation heating of the superconducting magnets of the UNK is expected to occur in the region of matched straight sections (MSS) 1 and 4, where the beam abort and extraction systems are located. The problem is related, on the one hand, to an exceedingly low level of the tolerable energy deposition in the magnet coils, 0.5 mJ/g, and, on the other hand, to the fact that the energy stored in the beam is hundreds of MJ. Therefore a negligible fraction of particles lost on the machine elements can cause radiation-induced quenches of superconducting coils.

2. PROTECTION OF SUPERCONDUCTING MAGNETS AGAINST IRRADIATION DURING EXTRACTION FROM THE UNK

The typical operational mode will include ten-fold fast resonance extraction done simultaneously with slow one[1]. The beam loss on the electrostatic deflector is about 2% of the intensity extracted.

The numeric simulation of beam extraction and particles hitting the plane of the electrostatic septum[2] gives the phase volume, angular and radial distributions of these particles at the input of the electrostatic deflector (fig.1).

When a fraction of the beam is lost on the electrostatic septum, the superconducting magnets are irradiated by the particles emitted from it. These particles may be divided into two groups: i) secondary neutrons, γ-quanta, and charged particles having an energy of $E \lesssim 0.7\ E_o$, ii) protons with $E > 0.7\ E_o$. Here E_o is taken to mean the proton beam energy.

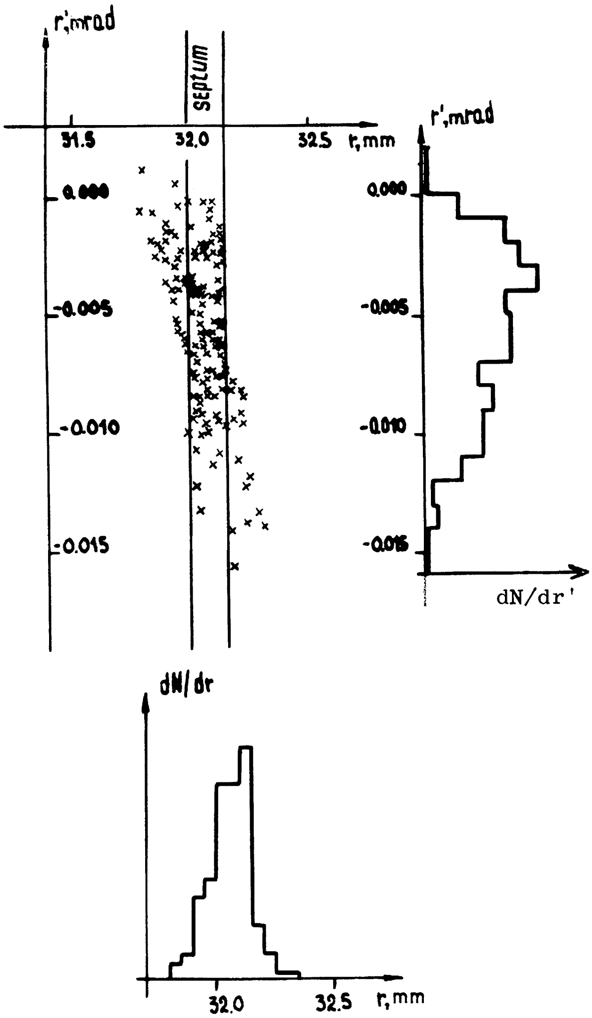

FIGURE 1. The phase space, angular and radial distribution of particles hitting the electrostatic septum.

The particles of the first group are localized in the straight section downstrean the 1st superconducting quadrupole lens Q13F[3]. Local orbit distortion in the vertical plane is produced with the help of "warm" magnets B1-B5. In this case, as seen from fig.2, the secondary particles are absorbed by the matter of collimators C1 and C2. Only the protons with $E > 0.7\ E_0$ passing through the aperture of these collimators cause the radiation heating of the superconducting magnets. Collimator C3 installed at a quarter of the wavelength of betatron oslillations downstream the electrostatic deflector localizes an appreciable part of the protons of this group. The dashed line in fig.3 shows the distribution of energy loss with collimator C3 placed in the structure.

Note that with the loss shown in fig.3, the amount of the energy deposited in cold-iron superconducting dipoles is ~ 0.1 mJ/g pulse. This raises the coil temperature during fast heat release by 0.2 K. The peaks in the loss distribution fall at those azimuthes of the machine where the dispersion function reaches its maximum.

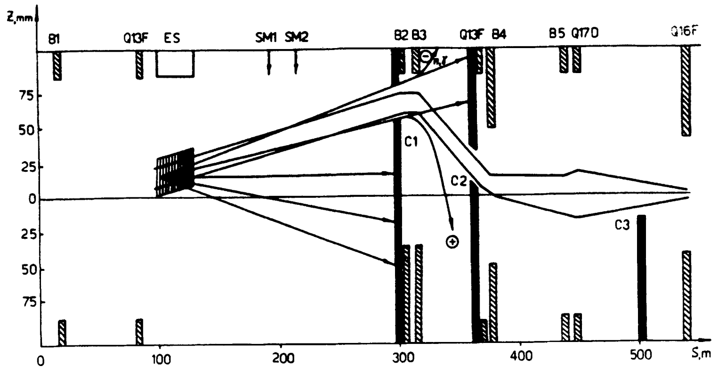

FIGURE 2 The localization scheme of neutral (n, γ), negatively charged (-) and positively charged, E E_s (+), particles emitted from the septum wires.

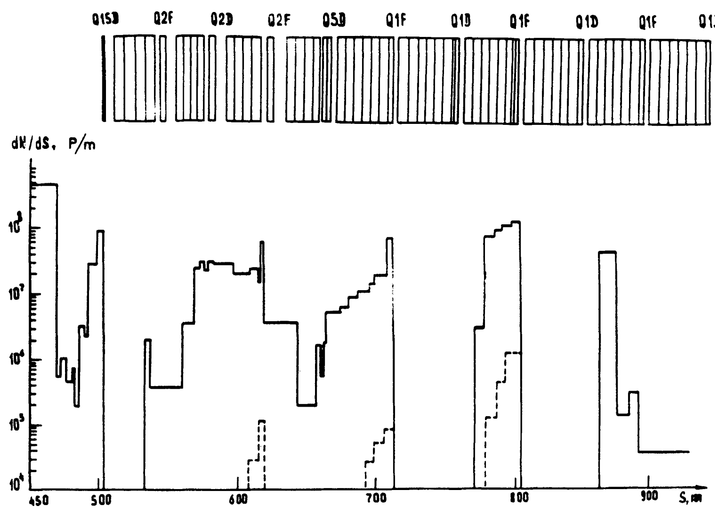

FIGURE 3 The distribution of proton loss in the UNK for $6 \cdot 10^{13}$ extracted protons. The solid histogram shows the distribution without collimator C3 and the dashed one shows it with C3 used.

3. PROTECTION OF ACCELERATOR MAGNETS AGAINST IRRADIATION DURING BEAM ABORT AND LOSS LOCALIZATION IN THE UNK

The system of loss localization allows one to intercept protons left uncaptured into the bucket in the beginning of the acceleration cycle and also to form the beam with the specified transverse emittance.

Figure 4 presents the layout of the elements of the system of loss localization in the superconducting stage of the UNK. A loss is intercepted separately in the horizontal and vertical planes.

When the emittance is formed in the vertical plane the beam edge is retained near the tungsten target T2 placed at the input port of absorber S2. Scattering in the target matter raises the amplitude of betatron oscillations of protons and they are intercepted onto the absorber. In the case of loss localization in the horizontal plane the beam edge is kept close to the scattering target T1 placed at the input port of septum magnet SM1. In the process of an increase in the amplitude of betatron oscillations a fraction of the beam is intercepted into the aperture of SM1 and extracted onto the external absorber.

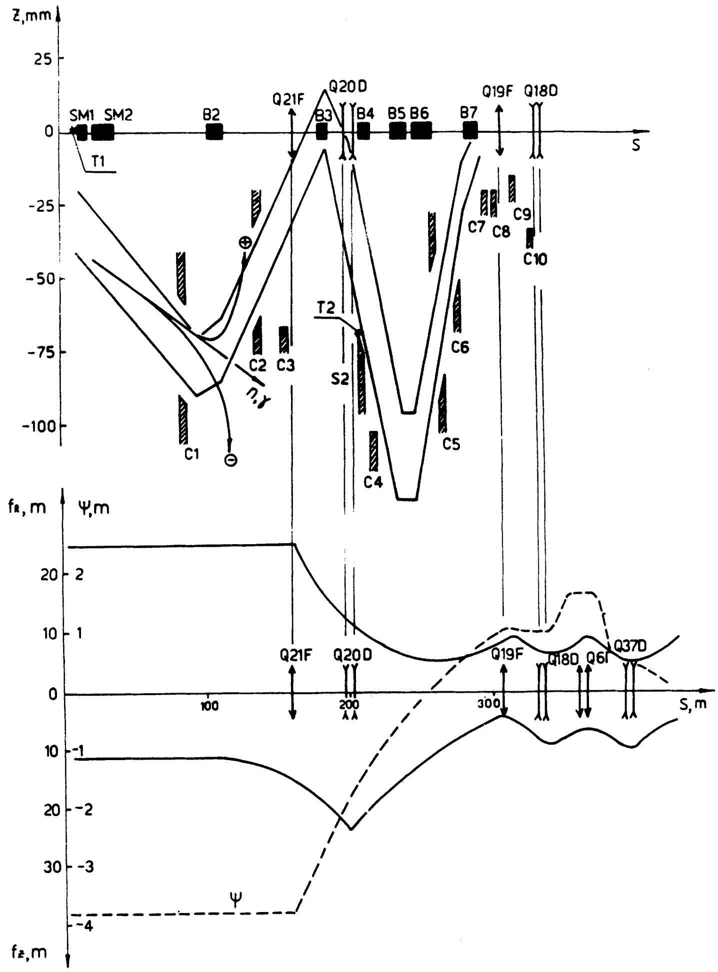

FIGURE 4. The section of MSS1 for intercept and loss localization in the 3d stage of the UNK. The solid lines show the amplitude functions in the R and Z planes, the dashed lines show the dispersion function. Q - superconducting quadrupole, B2-B7 - bending magnets, C1-C10 - collimators, SM1, SM2 - septum-magnets, S - scraper, T- target.

If a high dispersion, $\Psi = -3.9$ m, is produced where the septum is located, the protons having large momentum deviations at any amplitudes of betatron oscillations hit the target and are transferred further into the beam abort line.

The secondary particles emitting from the targets, electrostatic septa, from the absorber material as well as the protons acquiring a large increase of the amplitude of betatron oscillations as a result of interaction with the targets may be lost in the regular part of the machine during the 1st revolution. These particles are localized by a system of collimators C1-C10 whose operational features are similar to those of the collimators used during beam extraction.

As to their operational features, these collimators can conditionally be broken into 3 classes: constant-aperture collimators (C3, C4, C8, C10), those with an adjustable position of plates (C1, C2) and those with plates varying their position during the acceleration cycle (C5, C6, C7, C9).

Figure 5 presents the distribution of loss density in the part of the UNK. As was assumed, 1% of the total intensity of the protons having an inadmissibly large amplitude of betatron oscillations was localized in the horizontal and vertical planes and 1% of the beam intensity not captured into the acceleration mode. As is seen from the figure, the maximum loss in the UNK lattice does not exceed 10^7 p/m leading to the radiation heating of the magnet coils by $\Delta T \sim 0.1$ K. In the remaining part of the ring, the loss level does not exceed 10^4-10^5 p/m coinciding approximately with that on a residual gas. With this loss, radiation heating is inessential.

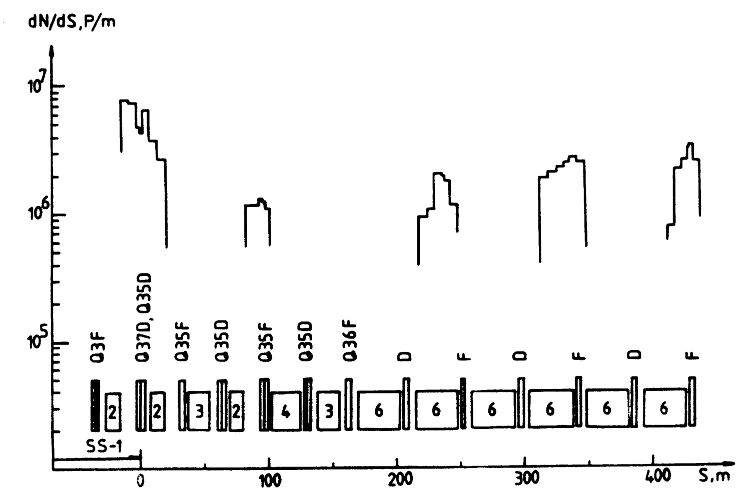

FIGURE 5. The loss distribution in the UNK ring tunnel during interception of 3% of the total intensity on the loss localization system.

Another source of a loss in MSS1 is the elements of the beam abort from the UNK. The mean frequency of triggering the beam abort system is supposed to be once per 10 acceleration cycles[4]. The most probable sources of loss are the beam abort septum-magnets of the 2nd and 3d stages of the UNK. The beam is transferred from the equilibrium orbit into the aperture of septum magnets with the help of the kicker magnet to be further dumped onto the external absorber over the beam abort line. A fraction of the beam may in this case hit the septum. This means that the situation is very similar to loss localization in the horizontal plane. Therefore it seems natural to assume that the protection measures against irradiation envisaged for operation of the loss localization system can also be applied for protection of the ring during beam abort.

To intercept low-energy and neutral secondary particles use is made of the local distortion of the closed orbit produced by the warm deflecting dump magnets placed directly behind the septum magnet and also of 3 collimators C1-C3 (see fig.4). Since beam abort may be possible at any instant of the acceleration cycle, the local orbit distortion is maintained constant up to 3000 GeV. As in the case of operation of the loss localization system, collimators C7, C9 (see fig.1) make it possible to intercept high-energy protons leaving the septa. The operational principle of these collimators is treated in detail in ref[5]. According to the calculations, when the plates of the movable collimators C7, C9 are placed at a distance of 5-7 mm from the edge of the circulating beam, the loss level in the UNK will not exceed 10^6 p/m if 1% of the total beam intensity interacts with the septum. In this case, the heating of the ring dipoles will not exceed 0.1 K. Therefore the superconducting magnets of the ring are protected without introducing additional collimators into MSS1.

4. CONCLUSIONS

The UNK project envisages the following measures protecting the superconducting magnets:

i) the loss localization system placed in MSS1 makes it possible to reduce the level of irradiation of the superconducting magnets by 3 orders of magnitude;

ii) the most complicated is the situation during beam extraction from MSS4. Here the elaborated protection measures allow one to decrease the level of superconducting magnet irradiation by about 2 orders of magnitude; besides, magnets having a better reserve in the current will be used in the section adjacent to it;

iii) when the injection, acceleration and extraction modes are violated the superconducting ring magnets will be protected by the beam abort system.

To conclude, it is worth noting that the elaborated measures of protecting the superconducting coils of the 2nd and 3d stages allow one to ensure the operational capability of the magnets and lenses during loss localization up to a few per cent of the design intensity at injection energy and also during extraction and beam dump onto the external absorber within the whole UNK cycle.

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