PROTECTION OF SUPERCONDUCTING MAGNETS AGAINST IRRADIATION DURING FAST RESONANCE EXTRACTION FROM UNK

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Abstract. This work presents the results on numeric simulation of particle loss and on the study of protection of superconducting magnets against irradiation during fast resonance extraction from UNK. Application of the system of local orbit distortions and movable collimators allows one to bring the radiation heating of the superconducting coils of the accelerator magnets below the tolerable level.

I. INTRODUCTION

A major problem of accelerators with superconducting magnets is radiation heating of magnet coils. This problem is related, on the one hand, to an exceedingly low level of the tolerable energy deposition in the magnet coils, 0.1-1 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 (SCC). The most hazardous conditions occur in UNK during fast extraction of the beam accelerated to 3000 GeV [1, 2]. Special measures enabling one to reduce essentially the amount of energy deposited in SCC [1-4] are elaborated to protect the superconducting ring magnets against irradiation.

The purpose of the present work is the numeric study of the beam loss during resonance extraction from UNK and also the optimization of the parameters of the system protecting the ring magnets against irradiation.

2. BEAM EXTRACTION FROM UNK

Slow and fast resonance extraction of the 3000 GeV beam from UNK will be done during the 40-sec field flattop. The beam may be extracted using the 3d-order resonance excited by the sextupole field or the 2nd-order one excited by the octupole field and gradient distributed along the ring.

The typical operational mode will include tenfold fast resonance extraction done simultaneously with slow one. There are two ways of 2-msec fast resonance extraction from UNK [5]. In the first case, protons are pushed out beyond the stable motion region with a kicker magnet, which causes fast coherent excitation of their betatron oscillations. In the second case, the stability region is compressed quiclky by decreasing the distance to the resonance line $\Delta Q=Q-Q_{res}$. ΔQ is varied with the help of a 2-msec semisinusoidal current pulse applied to the quadrupole. Figures 1a,b present the current pulses of extracted protons for the first and second extraction methods.

The beam loss on the electrostatic deflector is about 2% and depends weakly on the resonance order chosen for fast extraction.

3. NUMERIC SIMULATION OF EXTRACTION

The numeric simulation of beam extraction from UNK was done using the TWODIM code. The resonance harmonic of the sextupole field was produced using 320 sextupole correctors broken into 4 groups with 80 correctors in each. Such a system makes it possible to vary the phase of the resonance $3Q_r=K$ harmonic, zeroize

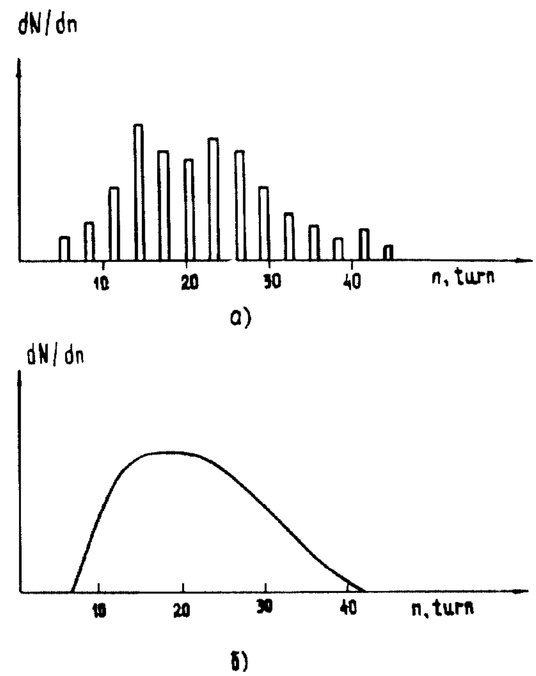

Fig. 1. The current pulses of extracted particles for coherent (a) and fast resonance (b) extraction from UNK.

the force of the coupling resonance $2Q_z+Q_r=K$ and to produce the chromaticity required for slow extraction.

The frequencies of betatron oscillations were varied slowly to drive particles to the resonance with the help of 160 quadrupole correctors. Proton motion in the sections between the lenses was calculated from the matrices.

In the initial operating point, the circulating beam contained 10000 particles having the Gaussian momentum distribution with $\sigma_{\Delta p/p}=1\cdot 10^{-4}$, Rayleigh amplitude distribution and uniform distribution over the phases of betatron oscillations in radial and vertical planes. This distibution corresponded to the E=0.2 mm·mrad emittance in either plane at a level of 95%.

The particles hitting during extraction the front, inner or outer with respect to the circulating beam, plane of the electrostatic septum, are the initial ones used for the calculation of secondary fluxes. Figure 2 presents the phase volume, angular and radial distributions of these particles at the input of the electrostatic deflector.

The value of the loss on the electrostatic septum is dependent on its orientation with respect to the circulating beam (see fig. 3). The minimum value is 1.7% for the septum slope angle r'= -0.001 mrad and is in a good agreement with the theoretical value given in [1]. It should be noted that for r'< -0.005 mrad, when the contribution from the proton loss on the inner surface of the septum is appreciable, the distribution of these protons along the deflector length is actually uniform. The loss on the outer surface (the dashed line in fig. 3) is concentrated along the first

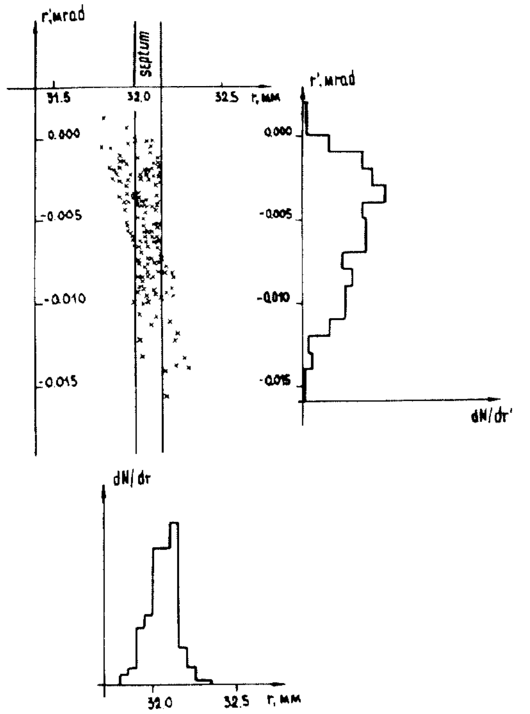

Fig. 2. The phase space, angular and radial distribution of particles hitting the electrostatic septum.

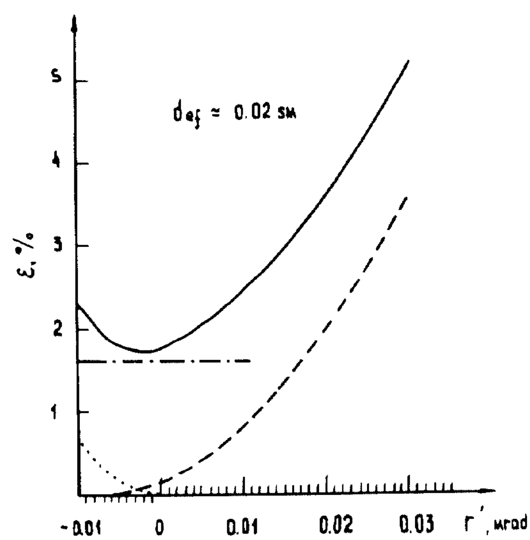

Fig. 3. Beam loss on the electrostatic deflector for fast resonance extraction from UNK versus the septum orientation. -.- beam loss on the septum front plane, ... loss on the inner side of the septum, --- loss on the outer septum side.

meters of the septum due to beam deflection by electrostatic field.

4. PROTECTION OF SUPERCONDUCTING MAGNETS AGAINST IRRADIATION DURING FAST RESONANCE EXCTRACTION FROM UNK

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 $E \leq 0.7\ E_0$, ii) protons with $E > 0.7\ E_0$. Here E is taken to mean the proton beam energy.

The particles of the first group are localized in the straight section downstream the first superconducting quadrupole lens Q18F [1]. Local orbit distortion in the vertical plane is produced with the help of "warm" magnets BMV2-BMV5. In this case, as seen from fig. 4, 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 radiation heating of the superconducting magnets.

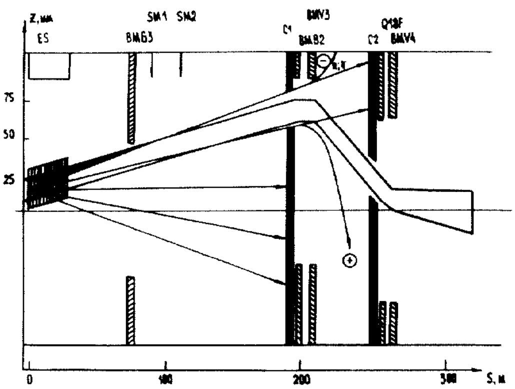

Fig. 4. The localization scheme of neutral (n, γ), negatively charged (-) and positively charged, $E < E_S$ (+), particles emitted from the septum wires.

To calculate the coordinates of the $E > 0.7\ E_0$ protons emitted from the septim wires, the ESSEPT code was applied. This code computes, according to the technique described in [6], the field in an electrostatic deflector with a wire septum. The diameter of each wire was 0.1 mm, the distance between their axes was 1.5 mm and they were distributed with respect to the septum axis uniformly to an accuracy of ± 0.05 mm. The strength of the electric field near the wires was described analytically [7]. To simulate transport of the protons scattered in the magnet structure the TURTLE code [8] was applied.

Figure 6 (the solid hystogram) shows the calculated distribution of the $E > 0.7\ E_0$ protons lost in the UNK ring.

High-energy protons can be localized in a straight section because of their different position in the phase space with respect to the circulating beam. Directly downstream the deflector, the angular divergence of the beam passed close to the septum is much less than that of secondary protons emitted from it. This leads to their spatial separation in a quarter of the wavelength of betatron oscillations. Putting here collimator C3 (see fig. 5) one can localize an appreciable part of protons emitted from the septum.

The protons left unlocalized by the collimators cause the radiation heating of the magnets of the ring part of UNK. The dashed line in fig. 6 shows the distribution of energy loss with collimator C3 placed in the structure. The peaks in the loss distribution fall at those azimuthes of the machine where the dispersion function reaches its maximum.

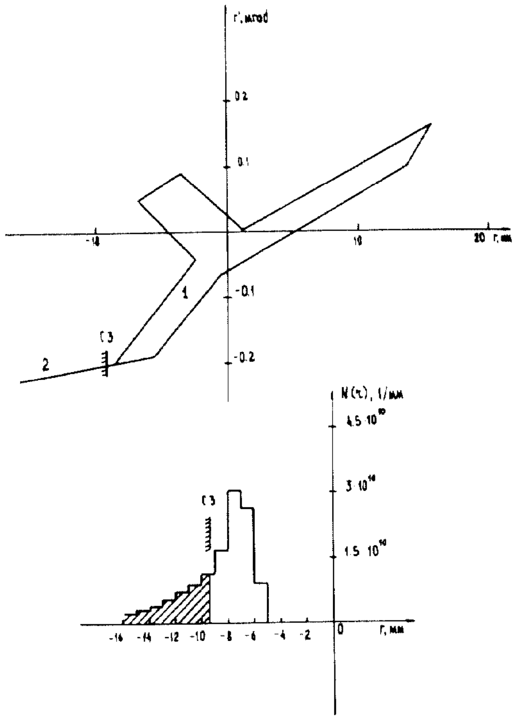

Fig. 5. The circulating beam during fast resonance extraction (1) and high-energy proton beam (2) produced in the septum matter as seen from a distance of $\sim$400 m from the septum. C3 is the collimator position for beam localization (2). The distribution of the beam density (2) is shown below. The dashed part of the hystogram shows the protons localized by the collimator.

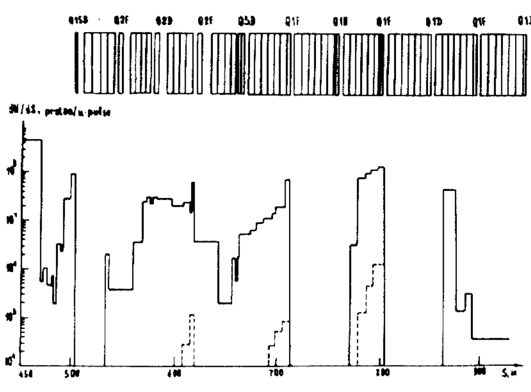

Fig. 6. The distribution of proton loss in UNK for $6 \cdot 10^{13}$ extracted protons. The solid hystogram shows the distribution without collimator C3 and the dashed one shows it with C3 used.

The loss distribution and amount are dependent both on the position of collimator C3 and on the septum orientation with respect to the section axis. Figure 6 shows the loss distribution for a septum angle r'=0mrad and with collimator C3 placed at a distance of $\sim$2.5 mm from the boundary of the circulating beam. With this distance increased up to 5 mm, the loss raises by 2-3 times.

Note that with the loss shown in fig. 6, $\sim 10^6$ prot/m, the amount of energy deposited in cold-iron superconducting dipoles is $\sim$0.1 mJ/g·pulse. This raises the coil temperature during fast heat release by 0.2 K. For a loss of $(2\text{-}3)\cdot 10^6$ prot/m the radiation heating will be 0.4-0.6 K. The choice of the operating parameters of UNK magnets envisages a reserve in the current for radiation heating of the coils. As seen from fig. 6, some groups of magnets will operate under a higher level of radiation-induced heat releases. That is why, according to the project, these magnets will have a higher temperature reserve.

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