A NEW BEAM EXTRACTION SCHEME FROM A SYNCHROTRON USING A MAGNETIC SHIELD AS A SEPTUM

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Abstract

A new scheme of beam extraction from a synchrotron is put forward. The main difference from other schemes of extraction is the use of magnetic shields instead of a septum. The magnetic shields are located in the central dipole magnets of a pulsed chicane. A magnetic shield is a multi-layer copper-iron tube. The presented numerical simulations and experimental results for the magnetic shields are in good agreement. The advantages and the area of application of the new extraction scheme are discussed. The proposed scheme will be used for extraction from the booster synchrotron to the storage ring of the new synchrotron radiation source in Novosibirsk.

INTRODUCTION

Usually one turn extraction from a synchrotron is done with a septum and a kicker [1], the septum being the most complicated part of this classical extraction scheme. The physical idea of applying a septum is to create a strong magnetic field separated with a narrow sheet from the orbit. There are two main principles of magnetic field separation in a volume. The first idea is to put there a thin septum sheet of a ferromagnetic material (typically iron) perpendicular to the magnetic field flux. Those are the Lambertson septa, which allow using a direct current power supply. However, one pole of the Lambertson septum is a septum sheet, where there is no space for a coil; therefore, a coil can only be made around the second pole. This leads to a considerable edge field at the synchrotron orbit. The second idea of applying a septum is to separate the magnetic field using the skin effect. Therefore, a short impulse of magnetic field must be created and a copper septum sheet must be used. If a vacuum chamber is located inside the septum, whirling currents may occur in the chamber, creating field perturbation. Inclusion of a septum inside the vacuum chamber requires additional complication of the extraction system. In this paper, an extraction scheme based on magnetic shields instead of a septum is discussed (fig. 1). In this method a pulsed chicane is installed after the kicker. The magnetic shields are located in the two central dipole magnets of the chicane. Magnetic field in the chicane dipoles increases before extraction and moves the orbit closer to the magnetic shields. Then the kicker shifts the beam trajectory and it goes through the shields which are inside the two central magnets. As a result, the beam goes to the outlet beamline.

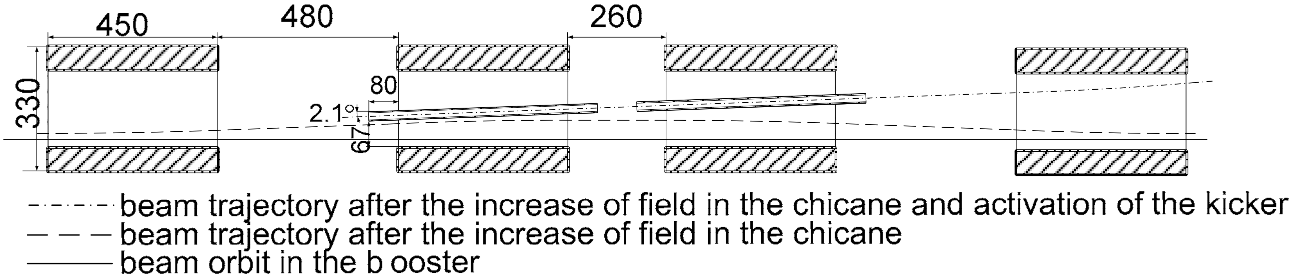

Figure 1: Scheme of extraction from a synchrotron through a magnetic shield. All sizes correspond with the project of extraction system for the booster of the new Novosibirsk SR source.

THEORY

The main problem of the proposed scheme is the perturbation of the homogeneous field near the magnetic shield in the dipole gap. The quadrupole part of the field perturbation leads to appearance of an additional field gradient in the design orbit. Unfortunately, this extra gradient alters betatron frequencies. If betatron frequencies become close to the resonance ones, the beam can be lost. Higher multipoles of the field perturbation decrease the dynamic aperture and increase the effective emittance. Therefore, the overall extraction efficiency can decrease significantly.

The proposed extraction scheme will work only if the magnetic shield does not alter the outside magnetic field. The magnetic field is not changed only if the shielded magnetic flux is equal to the flux flowing through the shield walls. Therefore, our goal is to match these two fluxes.

The shielded flux is the flux which is pushed out from the shielded area. This flux is proportional to the magnetic field in the dipole and to the cross-section of the shielded area. If a simplest pulse generator feeds the magnet, both the magnetic field and the shielded flux have a sinusoidal time dependence.

The flux flowing through the shield walls obviously depends on the nature of the material of the shield. A numerical simulation performed in COMSOL 3.2 [2] has shown that one of the possible solutions is to use layered iron and copper foils. The thickness of these foils should be about 0.1mm. A thicker foil is not flexible enough for making a magnetic shield by winding one foil above another. If the magnetic shield is made of a foil thinner than 0.1 mm the total volume of the spaces between the layers increases, thus increasing the overall shield size. A bigger size obviously leads to a greater perturbation. Further simulation in COMSOL has shown that the magnetic flux flowing through the multilayer copper-iron shield walls is linearly dependent on time (fig. 2).

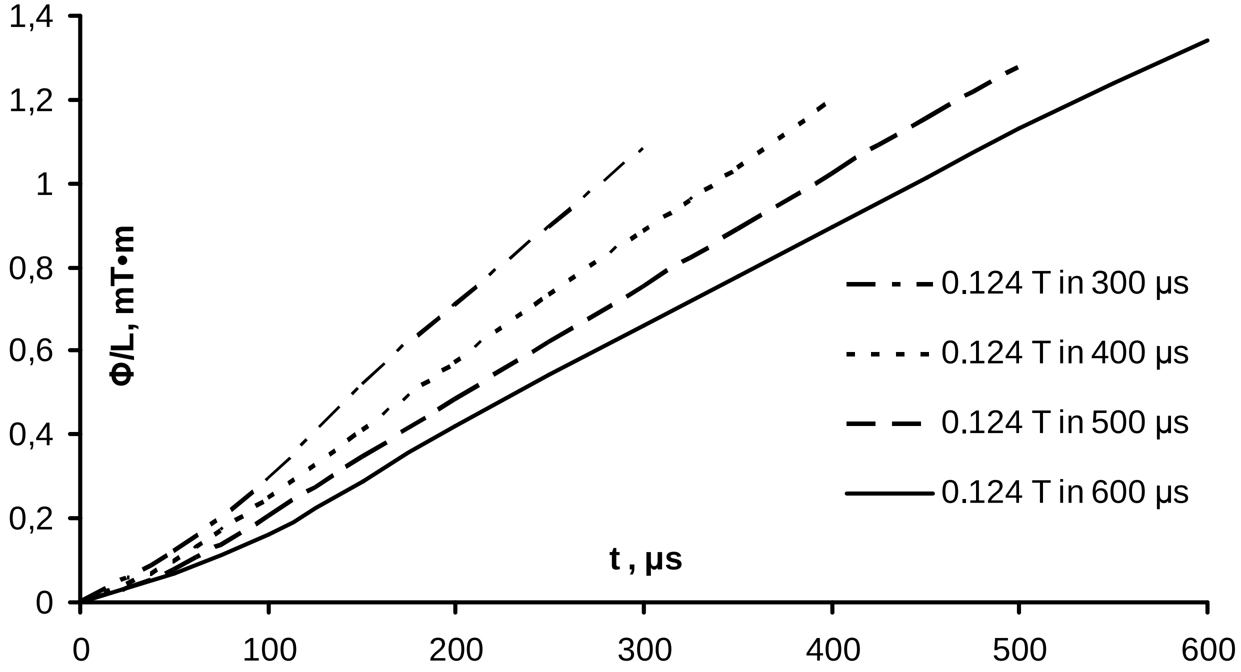

Figure 2: Flux flowing through the multilayer copper-iron shield wall per unit of length depending on time (t) and rate of the outer magnetic field rise.

Eventually, we have to match the shielded flux being a sine function of time with the flux flowing through the shield walls depending linearly on time. With some success, we can do it for times when the sine function behavior is close to linear.

The influence of field perturbation on beam dynamics in a synchrotron was estimated. A system for extraction through a magnetic shield from the booster of the new Novosibirsk SR source [3] was designed (fig. 1, tab. 1). Field perturbation near the magnetic shield was numerically simulated. Integrated focusing with field perturbation was calculated as a function of time. The maximum of integrated focusing is 0.005 m-1. It does not shift the betatron frequencies to a resonance. The nonlinear particle dynamics caused by the field perturbation were also simulated by the tracking method (fig. 3). The booster optics was supposed to be linear in the simulation. The field perturbation was supposed to be concentrated, and so it made a nonlinear kick on a particle.

Table 1: Design parameters of the new Novosibirsk SR source.

Beam energy		2.2 GeV
Time since chicane activation till extraction completion		2 ms
Field in the dipoles at the instant of extraction		0.5 T
magnetic shield size:	inner semi-axes	6 mm, 12 mm
	outer semi-axes	11 mm, 17 mm

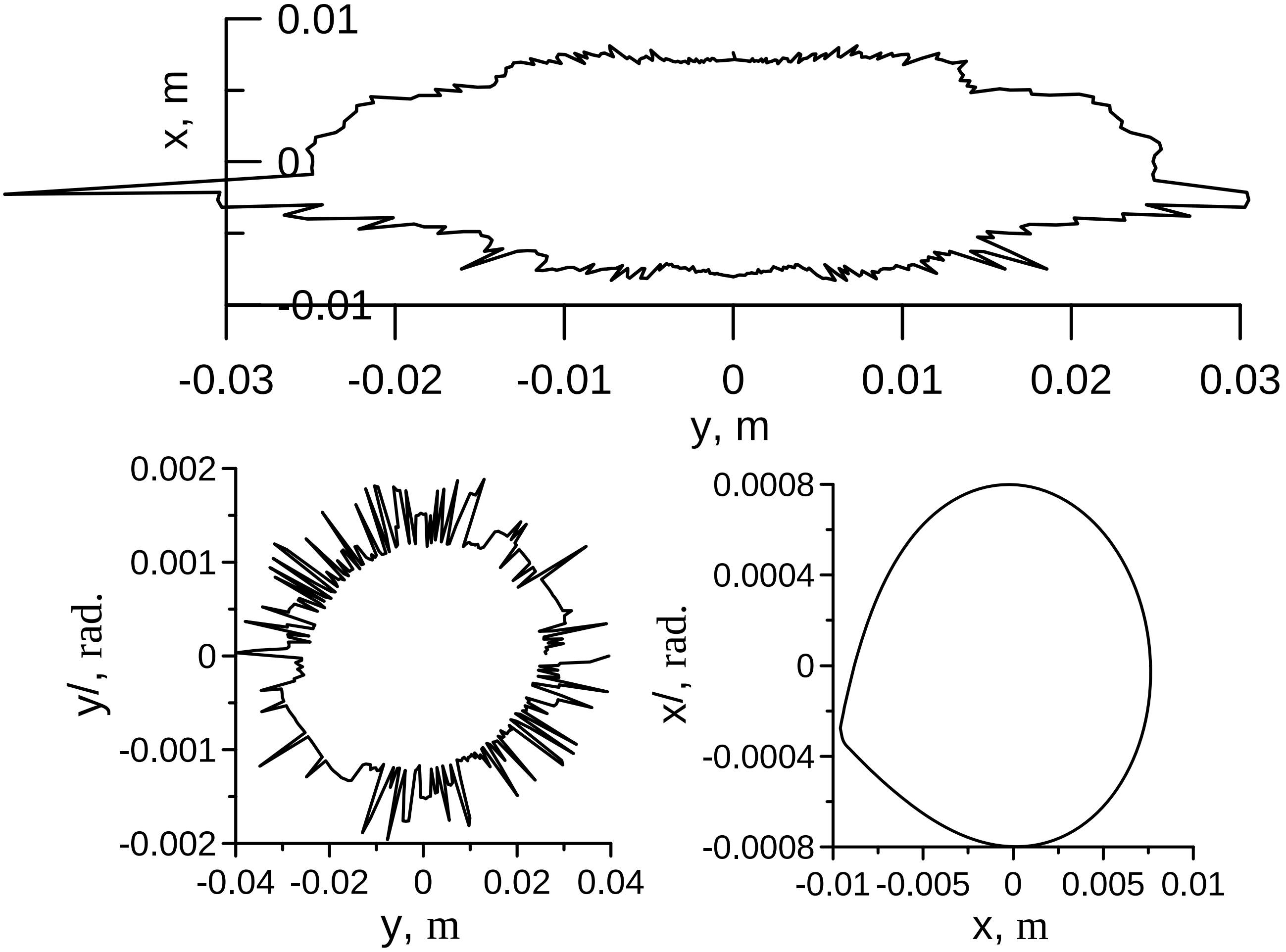

Figure 3: Simulation of a dynamic aperture at the instant of extraction is a result of the field perturbation near the magnetic shield. x, y, x/, y/ are the particle coordinates.

EXPERIMENT

The goal of the experiments was verification of the physical model and numerical methods used for the numerical simulation of field perturbation by a magnetic shield. For this purpose a magnetic shield was made and installed into a pulse magnet. The magnetic shield length was 200 mm; its inner radius was 6 mm and the outer radius was 9.5 mm. The pulse magnet gap height was 40 mm; its width was 40 mm and the magnetic length was 123 mm.

Measurements of field perturbation near the magnetic shield were performed using a search coil. The perturbation field is much less than the main dipole field. So the search coil was situated transversely to the main dipole field in order to suppress its signal. This method allows avoiding the influence of pulse generator instability on the results of measurement. Imprecise orientation of the coil axis can affect the accuracy of measurement. To avoid that, the measurements were done at points 1 mm up and 1 mm down the dipole axis. The gradient of field perturbation was calculated from the difference of measurements at these points. The measurements were performed at a distance of 17.5 mm from the shield centre for a variety of field rise rates. It was found that the perturbation was minimal when the rate of field rise was about 0.124 T per 300 μs. The gradient depending on the distance to the shield centre and the time since dipole activation was measured for this optimal case. The distribution of field perturbation was reconstructed from this measurement (fig. 4.). Magnetic field gradient at the dipole edge was also measured. The measurements showed that perturbation field at the edge of dipole was lower than at the dipole centre.

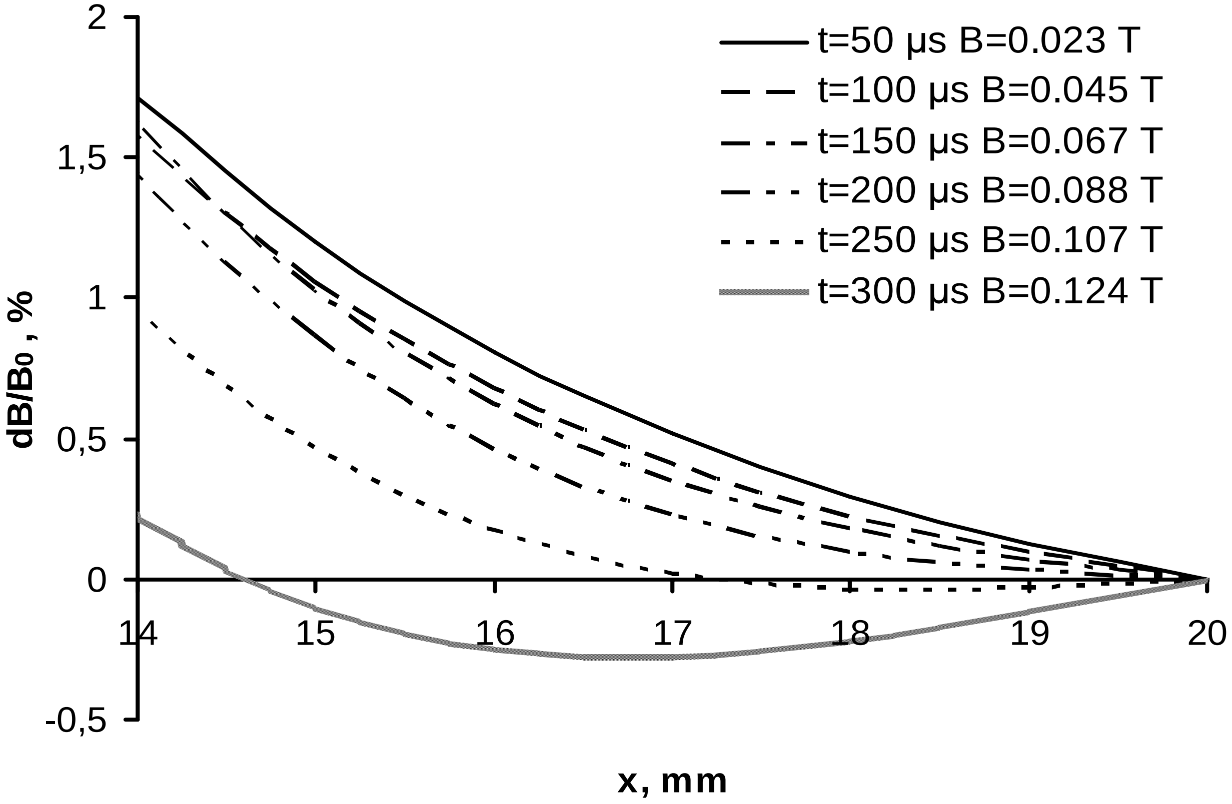

Figure 4: Distribution of field perturbation (dB) near the magnetic shield at the dipole centre as restored from the results of measurements. B0 is the main field at the instant of extraction; x is the distance to the shield centre and t is the time since dipole activation.

To simulate field perturbation near the magnetic shield at the dipole center, the relative permeability of the iron foil was measured as a function of magnetic field. Two series of measurements with different generators and toroidal solenoids were performed. Current in the solenoids and magnetic flux in the cores were measured. To measure the flux in the core, the secondary coil voltage was integrated with an integrating circuit. The relative permeability of the iron foil as a function of the magnetic field was reconstructed from these measurements (fig. 5).

The simulation of field perturbation near the magnetic shield was done using the measured dependence of the relative permeability on the magnetic field. A linear approximation was used for unknown values of relative permeability. It was found that the perturbation was minimal when the rate of field increase was about 0.124 T in 360 μs. Distribution of field perturbation in this case is shown in figure 6. The simulated optimal rates of field rise and magnitudes of perturbation almost coincide with the experimental ones.

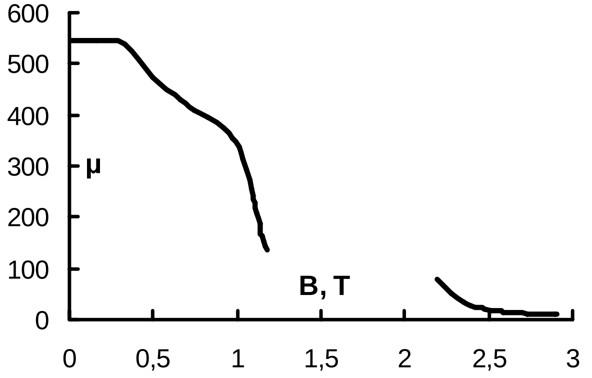

Figure 5: Relative permeability (μ) of iron foil is a function of magnetic field (B). Each curve corresponds to one series of measurements.

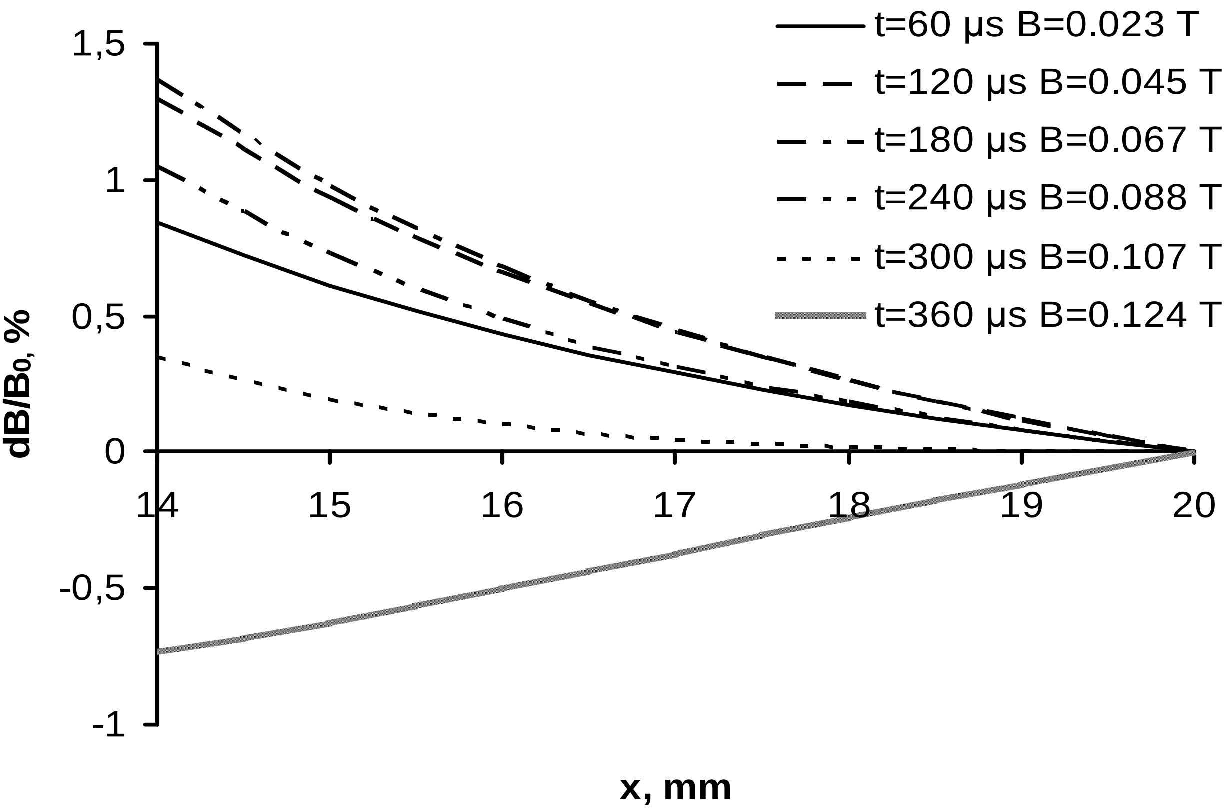

Figure 6: Distribution of field perturbation (dB) near the magnetic shield at the centre of dipole as a result of the simulation. B0 is the main field at the instant of extraction; x is the distance to the shield centre and t is the time since dipole activation.

RESULTS

A new scheme of extraction from a synchrotron is proposed. The advantages of the scheme are compactness and absence of septa. Field perturbation near a multilayer copper-iron shield was measured. The perturbation of magnetic field was shown to be low. The results of the simulations are in agreement with the experiments within an acceptable accuracy. A project of an extraction system from a booster of an SR source through a magnetic shield has been developed. The influence of field perturbation on particle dynamics in a booster is within tolerable limits.

REFERENCES

[1] K. Wille The Physics of Particle Accelerators: An Introduction. New York: Oxford university press, 2000
[2] http://www.comsol.com/
[3] E.I. Antokhin, A.A. Gvozdev, G.N. Kulipanov, et al. NIM A, 2007, volume 575, issues 1+2, p.