FAST MAGNETIC KICKERS FOR THE NSLS-II BOOSTER SYNCHROTRON: DESIGN AND TEST RESULTS*.

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Abstract

For the purpose of realization of single-turn injection and extraction from the NSLS-II booster synchrotron, BINP members created nanosecond non-vacuum ferrite kickers with fronts of pulsed magnetic field of ~ 200 ns, flat-top duration of 300 nsec and its instability of 0.2÷1% at most. This paper describes the design of unique kicker magnets with ceramic vacuum chambers with deposited longitudinal strips of titanium nitride (TiN) inside. The paper also presents the results of bench tests of the kickers: oscillograms of current pulse in bus bars, the shape of the pulsed magnetic field, and transverse distribution of the longitudinal field integral in the kicker aperture.

INTRODUCTION

They at Brookhaven National Laboratory (BNL, USA) have been actively working to create a third-generation national synchrotron light source (NSLS-II). The project includes an injection linac, booster synchrotron for the total energy of the storage ring and electron storage ring for an energy of 3GeV [1].

BINP has developed the booster synchrotron for this project. The booster is to accelerate the electron beam from the minimum energy of the injector (170 MeV) to the total energy of the storage ring (3.15 GeV) with an average beam current of 20 mA. In addition, the synchrotron is to provide both one-bunch and multi-bunch modes of accumulation of the particles.

One of the main systems of the synchrotron is the system for beam injection and extraction, which shall comply with stringent requirements. According to the technical specifications, the total angular deflection of the beam extracted from the booster (dX`), caused by instability of the injection-extraction system, should not exceed 20% of the total angular spread of the beam. This necessitates smoothness in the vacuum chambers of the injection and extraction kickers and high of stability of nanosecond pulses acting in them.

MAIN PARAMETERS OF THE INJECTION-EXTRACTION KICKERS

Coils of the kickers are located outside the vacuum chamber, which is made of ceramics and has inner titanium nitride coating.

For the purpose of unification of fabrication, testing and assembly, the kicker magnets are made as sections with equal apertures and effective lengths. Injection is performed with four separated sections, each powered from a separate pulse modulator. In the extraction mode, the same four sections are connected via flanges in a single module. In this case, one modulator feeds two sections in parallel. Such a sectioned design allowed charging voltages of at most 25 kV and on the pulse forming lines of the pulse modulators and 20 kV on the inputs of the kickers, respectively.

Table1: Main Parameters of the Injection-Extraction Kickers.

Parameter	Injection	Extraction
Beam deflection angle, mrad	17	6.3
Magnetic field, T	0.055	0.076
Aperture, mm	20×60 (ellipse)	
Effective length of magnet, mm	207	
Magnetic gap, mm	38	
Pole gap, mm	84	
Inductance, nH	600	
Current in bus bars, A	1650	2300
Pulse flat-top duration, ns	305÷335	
Pulse rise/fall time, ns	170/220	220
Inhomogeneity of the flat-top of field pulse	$\pm 5\cdot 10^{-3}$	$\pm 2\cdot 10^{-3}$
Voltage across bus bars, kV	17	20

Table 1 presents the main parameters of the kickers, and Fig. 1 shows the extraction kicker installed in the ring of the booster.

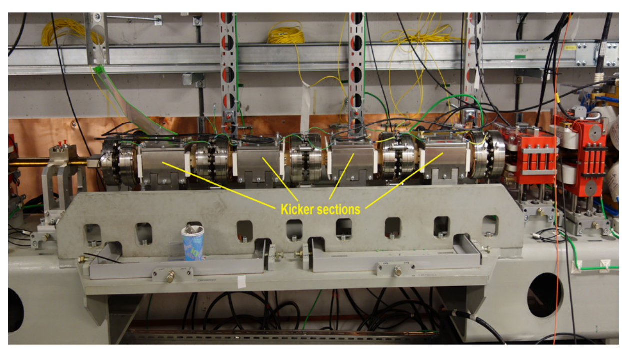

Figure 1: Extraction kicker in the extraction interval of the NSLS booster.

FEATURES OF THE KICKERS.

Fig. 2 and Fig. 3 show the structure of one injection kicker section on a separate mounting plate. The magnetic core is made of CMD5005 ferrite 25 mm thick. Deviation of the transverse and longitudinal dimensions of the bars is not more than ± 0.05 mm and ± 0.1 mm, respectively. The required accuracy of positioning of kicker relative to the equilibrium orbit of beam is attained due to the precision of manufacturing of the ferrite bars and metal

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details of the structure. The accuracy of installation of the bus bars is provided by positioning bars (5). The bus bars (Fig. 2, it. 4) are insulated with the organosilicon compound "Viksint" (10).

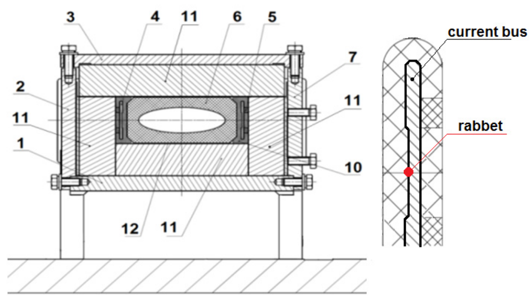

Figure 2: Design of one kicker section.

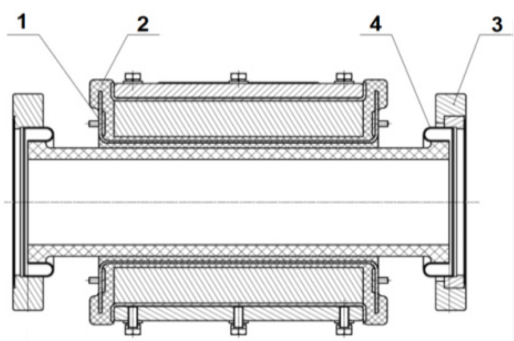

Figure 3: Longitudinal cross-section of the kicker section: 1 – contact pad, 2 - insulation, 3 – CF flange, 4 – kovar ring.

Plate insulation spacers (12), located between ferrite core (11) and ceramic chamber (6) on the top and at the bottom, are made of the same material. In the course of the assembly of the kicker, a frame of steel plates (1, 2, 3, 7) is compressing the magnet core. Due to the elasticity of the insulation material, the air gaps between the ferrite, coil and vacuum chamber vanish, which ensures the electrical strength of the structure.

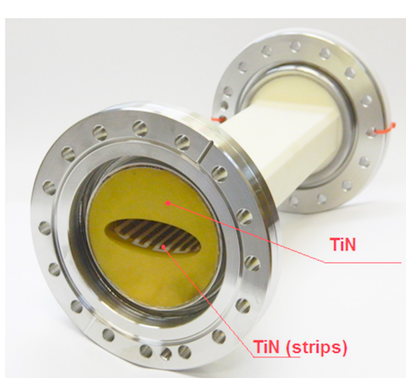

Figure 4: Ceramic vacuum chamber with strip titanium coating, assembled with the flanges.

The ceramic vacuum chamber (Fig.4.), manufactured by «FRIATEC AG» has an internal CVD coating of titanium nitride (TiN) 5 μm thick.

Unlike kickers with chambers with solid titanium coating [2, 3, 4], the coating in the BNL kickers is in the form of strips (Fig. 5).

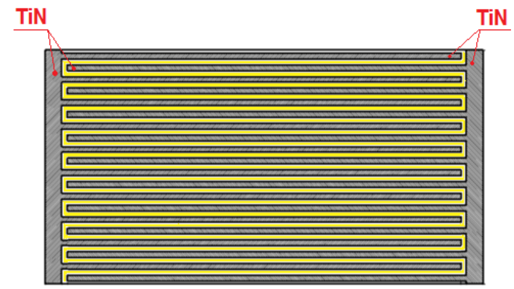

Figure 5: Configuration of the coating of the ceramic chamber.

The ends of the inner surface of the chamber have solid circular coating, which provides continuous contact with the coating on the front surface of the chamber and further with the flanges.

During the primary tests of the kickers, we faced a problem of overstress in the space between the strips on their sharp edges with a radius of less than 5 microns. That resulted in arcing in vacuum and distorted the pulse shape. To solve this problem we performed training of the chambers in vacuum. A sinusoidal voltage of a frequency of 50 Hz and amplitude of up to 10 kV was applied to the flanges of the chamber for several hours.

RESULTS OF SIMULATION OF MAGNETIC FIELDS IN THE KICKERS.

For assessment of the effect of the TiN coating on the qualitative parameters of the magnetic field, an ANSYS-2D simulation was carried out. Fig. 6 shows the change in the shape of the field pulse peak (dB/Bmax) for a chamber without coating, with a solid TiN coating 0.1 μm thick and with a strip TiN coating 5 μm thick.

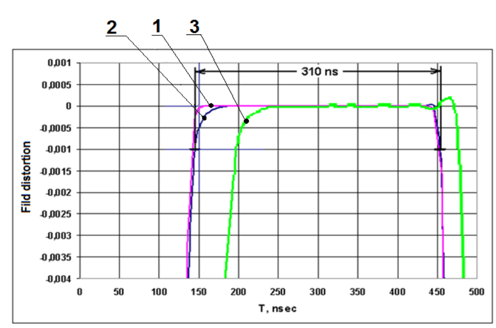

Figure 6: Effect of coating on the pulse flat-top: 1 - without coating, 2 – strip coating 5 μm thick, 3 - solid coating 0.1 μm thick.

One can see from the simulation results (Fig.6) that with the strip coating, irregularity of the pulse peak does not exceed 0.1%, which meets the necessary requirements. Solid coating cannot provide the required field rise and decay times (≤ 150 ns). Therefore, we chose a coating of strips of a width of 3.4 mm and with the same interval between them (Fig. 5). This configuration allowed us to minimize losses of the deflecting magnetic field ($\leq 2\%$) under condition that the required impedance of the chamber is provided.

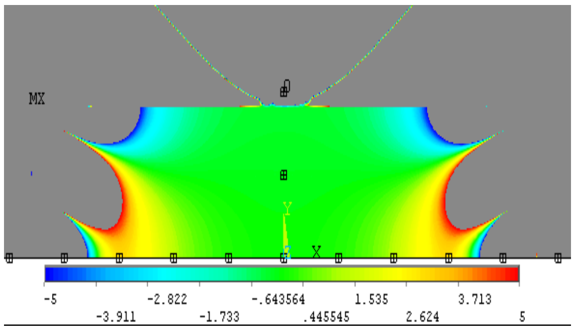

Figure 7: Field homogeneity $dB/B\times10^3$ on the top of pulse (for strip coating). One division in the horizontal and vertical scales corresponds to 1 cm.

To provide the required field homogeneity, we made rabbets in the bus bars (Fig. 2). Fig. 7 shows the result of the 2D simulation of field homogeneity in the center of the chamber on the flat-top of pulse.

RESULTS OF THE BENCH TESTS OF THE KICKERS

Transverse distribution of the longitudinal integral of magnetic field was measured for each kicker section. A single injection pulse modulator was used to energize the magnets in this test.

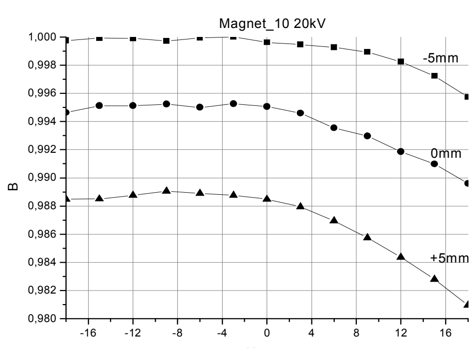

Figure 8: Distribution of the longitudinal field integral in the cross section of the kicker.

Fig 8 shows the normalized curves of B-field distribution for one of the magnets at 20kV charging voltage of the PFN which corresponds to ~490 G. Magnetization characteristic of the magnet is shown on Fig.9. The integral of magnetic field was measured in 3 horizontal planes: medium plane and two planes 5 mm above and below it. Fast digitizer ADC200ME was used for acquiring the signal from magnetic field probe - long single turn coil made on PCB

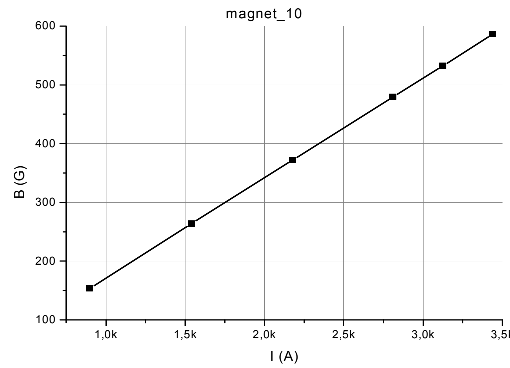

Figure 9: Magnetization curve of the kicker magnet I – total current of two buses.

All manufactured kicker sections assembled with appropriate pulse modulators were tested for pulse waveform compliance with the requirements. The integrated signal from long coil probe placed inside the ceramic chamber of the extraction kicker section is shown on Fig.10. This curve is a result of averaging among 128 shots of the pulser. Achieved parameters of the pulse are the following: rise time (0.3%-99.85%) 224ns, pulse top duration (99.9%) >330ns.

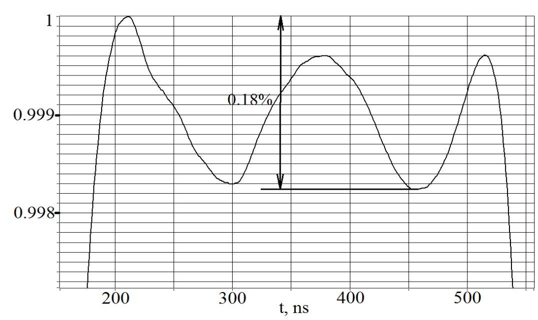

Figure 10: Normalized magnetic field waveform in the extraction kicker at 700G amplitude.

CONCLUSIONS

The kicker magnets for the NSLS-II booster have been successfully tested on a special test bench at BNL. Currently the kickers and supply modulators are being tuned directly on the booster ring.

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