MECHANICAL DESIGN OF A FERRITE-BASED INJECTION KICKER FOR SNS ACCUMULATOR RING*

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Abstract

Two sets of kickers, 4 pulsed dipoles in each set, will be used in the SNS accumulator ring to create a dynamic orbit bump for injection process. These kickers are designed as large aperture, window frame magnets. The design of these 8 kickers have been completed. The first article kicker has been assembled and is being tested. In this paper we discuss the mechanical design criteria for these kickers, the layout in the accumulator ring, the magnetic field requirements and the ferrite based magnet field analysis, the eddy current and thermal considerations in the choice of ceramic vacuum chamber and its implementation. Also we discuss a wedge shaped clamp which was designed to reduce the vibration in the coil when powered at the 60 Hz repetition rate.

1. INTRODUCTION

The injection of the SNS accumulator ring takes place in one of the straight sections of the ring. Two sets of kickers, two horizontal and two vertical in each set, are used to create dynamic orbit bumps to paint the phase space of the injected proton population [1].

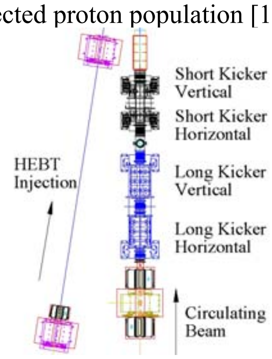

Figure 1: Upstream Set Of Injection Kickers

The injection kickers will be operated at a 60 Hz rate. The rise time and flat top time together are in the range of 2 to 3 ms. Ferrite is used as the core material for its high frequency response and low loss. The coils are wound with copper conductors and water-cooled. Since some heat will be generated in the ferrite and coil, the magnet is installed outside the vacuum system to prevent leaks from the water-cooling in the vacuum system. The vacuum chamber is made of alumina ceramic to avoid eddy currents induced by the pulsed magnetic field. The inner surface of the ceramic chamber will be coated with titanium nitride (TiN) to carry beam induced image current and reduce the secondary electron yield [2]. For simplicity, the horizontal magnets and vertical magnets are designed identically but oriented differently.

2. KICKER SPECIFICATIONS

Based on the beam dynamics, the eight kickers are designed as 4 long kickers and 4 short kickers. One set of 4 kickers is located upstream from the injection point. The sequence of kickers is long horizontal-long vertical-short horizontal-short vertical toward the injection point (Fig. 1). The other set of kicker is located down stream from the injection point with a mirrored sequence. The specifications of these kickers are listed in Table 1.

Table 1: Kicker Magnet Parameters.

	Long	Short
No. of Kickers	4	4
Ferrite Gap size: (cm)		
Height	19.55	21.55
Width	22.48	24.48
Length	64	21
Volume (cm^3)	81085	28313
Beam Pipe Material:	Ceramic	Ceramic
Inner Dia. (Aperture)	16 cm	18 cm
Turns per Coil	10	12
Max. Field (Gauss)	790	1000
Max Current (amps)	1230	1476
Ferrite Weight (lbs)	891	238
kicker assembly Weight (lbs)	1185	440

3. KICKER MAGNET

The fast kicker is designed as a ferrite core, rectangular window frame magnet (Fig. 2)

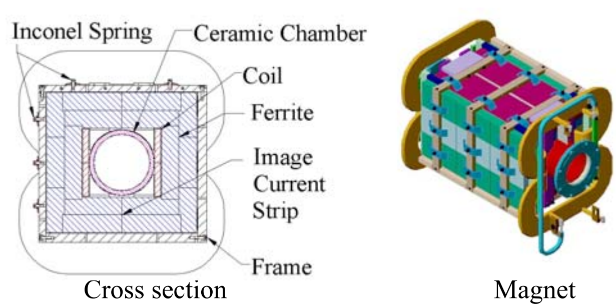

Figure 2: Injection Kicker Magnet

CMD 5005 Ni-Zn type ferrite is used for this magnet. This ferrite has high frequency response and very low eddy current loss. These properties are important for

*SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy. SNS is a partnership of six national laboratories: Argonne, Brookhaven, Jefferson, Lawrence Berkeley, Los Alamos, and Oak Ridge.
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pulsed magnet operation. The ceramic chamber is centered in the gap and supported independently to the platform. The coil is installed outside the ceramic chamber. The coil is made of two identical 5 turn coils stacked together with one rotated 180 degrees. One jumper bus connects these two coils to form a single 10 turn coil. The window shape core is formed by stacks of ferrite blocks. Since ferrite is very brittle, these blocks are clamped by inconel springs to a metal frame. In the middle of the back leg is a copper strip that will carry beam image current to reduce beam impedance. The other purpose of the strips is to damper beam induced pulsed fields in the ferrite core. Pulsed power is fed through bus bars in the end of the ferrite core by 4 cables for each polarity. Two kickers, one horizontal and one vertical, are installed on a common platform. These two kickers are constructed identically except one is oriented 90 degrees with respect to the other (Fig. 3). On the platform, each kicker has its own adjusting screws, so they can be surveyed and aligned to each other. When installed in the ring, the platform will be final aligned to the beam line by sliding pads in the support stand. The kicker assembly is covered by a full length metal cover (not shown), which is grounded for shielding.

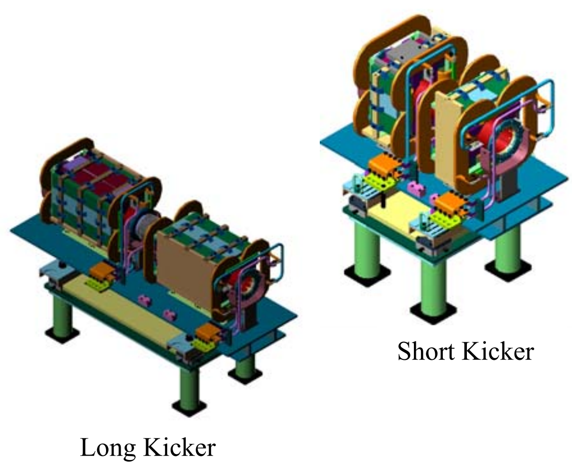


Figure 3: Injection Kicker Assembly

4. VACUUM COMPONENTS

The vacuum chamber is made of alumina ceramic with stainless steel flanges by metalized joints (Fig. 4). Helico-Flex type metal seals are used in the flange to protect the fragile joints. The number of bolts and required torque to tighten Helico-Flex seal are much less than for the conflat type. The inside surface of the ceramic chamber will be coated with copper and Titanium Nitride. Inconel spring fingers will be inserted and clamped in the two ends of the pipe to bridge the continuity between flange and inside coating. Low spring rate bellows will be used to connect ceramic pipe to other vacuum components in the system to compensate any misalignment and mechanical tolerances. These bellows are made of eight mil inconel sheets with a spring rate of 75 lb/in. All vacuum components will be cleaned and baked to 250 ^{0}C before assembled to meet the required vacuum quality of 1×10^{-8} torr range.

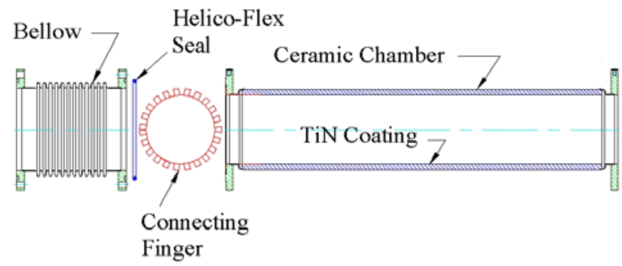


Figure 4: Vacuum Chamber Components

5. EDDY CURRENT HEATING

When operated at 60 Hz, the penetration of the magnetic field will induce eddy current in the inner coating of the ceramic chamber. The heat generated by this eddy current could reach around 100w/m along the center line. Calculation shows the maximum temperature rise in the chamber with a non-uniform distribution is about 46.8^{o}C (Fig. 5).

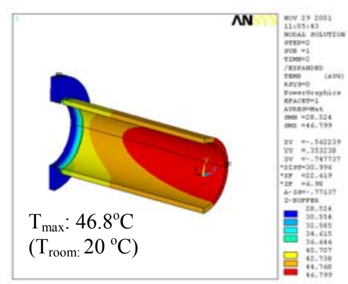


Figure 5: Eddy Current Heating In The Chamber

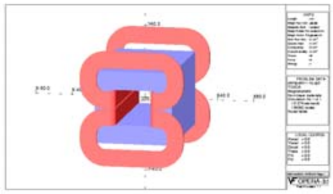
The induced thermal stresses in the transition joints are all in compression and are acceptable. Also, this ceramic vacuum chamber is specified to be baked to 450^{o}C for high vacuum quality. The heat generated from eddy current is acceptable for this beam chamber.

6. MAGNETIC FIELD CALCULATION

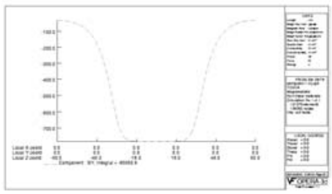
The injection kickers will create dynamic orbit bumps to paint the optimum phase space of the injected proton population. The required magnetic field quality for these kickers is the variation of integral field should be better than 1% [3]. An OPERA model was used to analyse its magnetic properties (Fig. 6). The results are listed in the table 2.

Table 2: Kicker Magnetic Properties

	Long	Short
Turns per Coil	10	12
Current (amps)	1230	1476
Center Field (gauss)	784.9	1006
Integral filed $\int$ Bdl	65850.9	43505.0
Variation	+/- 1.00%	+/- 0.92%
Effective length	83.9	43.2
Inductance	158.0 x 10^{-6}(H).	149.0 x 10^{-6}(H).



Magnet Model



Center Field Along Beam Line

Figure 6: Magnetic Field Plot

7. DAMPER AND COIL SUPPORT

When the first article long kicker magnet was powered to full current, the Lorentz force caused the coil to start a vibration of 60 Hz. From an OPERA magnetic analysis and an ANSYS harmonic analysis (Fig. 8), the magnitude of the harmonic force is about 40 lb in the straight part of the coil. Von Mises stresses are 1507 psi in the copper and 1000 psi in the epoxy. These stresses are well below the yield strength of the materials, but in order to reduce this vibration, wedge clamps were designed and installed in the corner of the gap to push against the coils (Fig. 7). Each clamp provides more than 100 lb preload to each coil, which reduces the vibration. Test data of vibration in the coil when operated with and without wedge clamps are listed in the table 3. This data shows the total displacement of vibration is significantly reduced to a reasonable level for operation when wedge clamps are installed.

Table 3: Vibration Displacement

	Without wedges Vibration displacement			With wedges Vibration displacement		
Current	+ mm	- mm	Total	+ mm	- mm	Total
1050	0.088	-0.092	0.179	0.062	-0.046	0.108
1250	0.170	-0.125	0.295	0.101	-0.058	0.160

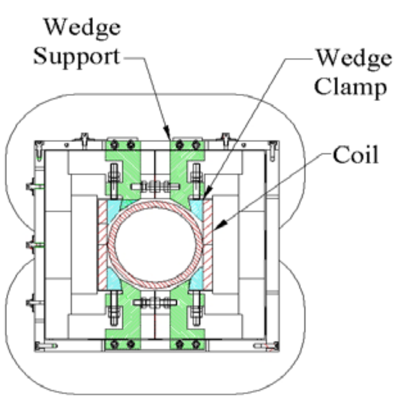
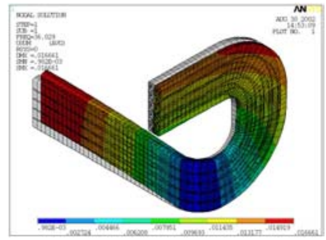
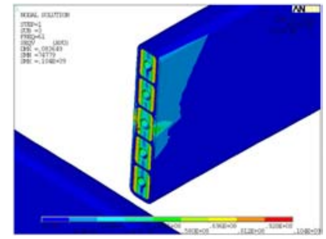


Figure 7: Wedge Clamps



Vibration Mode Shape



Harmonic Stress

Figure 8: Harmonic Analysis of Coil

8. FIRST ARTICLE ASSEMBLY AND TEST

The first article long kicker magnet (without the ceramic chamber) was assembled (fig. 9) and used to test all design criteria. The coils have passed all mechanical, electrical and hydraulic tests. Ferrite blocks were accurately machined and formed a nice tight window frame. The magnet has gone through full power tests and magnetic measurements. From these tests, this magnet meets the design requirements. Four ceramic chambers have passed all mechanical tests and vacuum leak checks. They are being coated with TiN in the vacuum Lab. These beam pipes will be installed into the magnet soon.

Figure 9: First Article Kicker Assembly

9. CONCLUSIONS

The first article injection kicker has been successfully assembled and tested. All components for the production kicker are in house except some ceramic pipes. Four of the 11 ceramic chambers are already in house and are being coated with TiN. The balance of the chambers will be delivered soon. The production kicker assembly work is in progress. The eight kicker assemblies will be completed in about six months.

10. ACKNOWLEDGEMENTS

The authors thank S. Henderson of ORNL for his valuable discussion on ceramic chamber coating .

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