# DEVELOPMENT OF FAST DECAY TYPE PULSED KICKER MAGNET FOR INDUS-1

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*Abstract*

A fast decay type kicker magnet has been developed for injection of two electron bunches (30 ns spacing) into 450 MeV storage ring (Indus-1). A kicker magnet system consists of a window magnet of lumped type fed by PFN. Kicker magnet is kept outside vacuum over a ceramic chamber and its coil is split into half turn for achieving a fast decay (< 150 ns). The magnet is excited by a pulse current with a rise time of 1.2 μs and exponential fall decay with a constant < 150 ns. A pulsed magnetic field of 800 G with a rise time of 1.2 μs and exponential decay of 125-130 ns was obtained. This paper presents, choice of ferrite, electrical and magnetic design, fabrication process, engineering challenges to meet decay requirements and performance results.

## INTRODUCTION

The Indus-1 Synchrotron radiation facility consists of a 20 MeV microtron injector, 700 MeV Booster synchrotron and 450 MeV storage ring provides the radiation in the VUV region of the electromagnetic spectrum.

In the single bunch mode operation in the storage ring (Indus-1), the equally spaced two bunches from Booster synchrotron are injected into storage ring which fill the buckets of Indus-1. Injection of two electron bunches into storage ring is made by fast decay type kicker magnet.

We successfully developed a compact and efficient kicker magnet system by using a combination of a lumped kicker magnet and PFN.

There are four-design options, which have been studied. These are (i) kicker located inside or outside the vacuum (ii) delay magnet or lumped magnet. Keeping in view of simplicity of construction, compactness, fast decay requirement and vacuum. Therefore, a lumped magnet outside the vacuum has been adopted as a fast decay kicker magnet in the present case.

## KICKER MAGNET SYSTEM

Two electron bunches spaced at 30 ns are required to inject into storage ring (orbit time 63 ns). The kicker magnet system is required to produce a pulse magnetic field with a rise time (1.2 μs) and exponentially fall ($B_z = B_0 e^{-t/\tau}$) with a decay constant ($\tau$) < 150 ns. The requirement of kicker system is very crucial for the excitation of kicker magnet in order to get such pulse waveform. The magnet configuration, Ferrite yoke and power supply combinely determines the fast decay characteristics of kicker magnet system.

### *Requirement of Magnetic Field Pulse Shape*

A pulsed magnetic field shape required for injection of 450 MeV electron beam into storage ring is shown in figure 1.

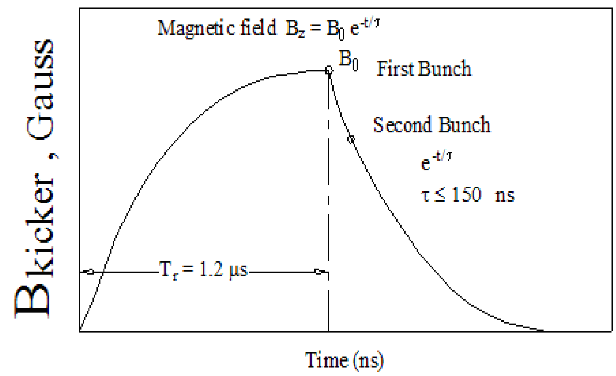


Figure 1: Injected electron bunches seeing the magnetic field of the kicker magnet.

The kicker magnet is excited linearly in 1.2 μs to produce on orbit bump of 16 mm de–excited linearly in < 150 ns. The electron beam injected at an angle of 2.5 mrad to the design orbit. With this angle, the electron beam can be injected at tune point (1.55, 1.56) with kicker is to be switched off in 125-130 ns. The electron bunches sees the falling part of the magnetic field of the kicker magnet.

Table 1: Technical Parameter of Fast decay kicker magnet

1. Kick Angle : 3 to 16 mrad
2. Pulse Shape : sinusoidal rise and exponential fall
3. Rise time : 1.2 μs
4. Fall decay : $\tau$ < 150 ns
5. Jitter : ± 5 ns

## FAST DECAY MAGNET

The main design criteria for the kicker magnet is to produce half sine wave rise time and exponential fall pulse response without any other beam perturbation. As magnet has to keep outside vacuum, space limitation and driving voltage below 30 KV. Keeping in view of all aspects, engineering design have been made and is presented together with a description of their sub systems.

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### *Selection of Magnetic Materials*

The required time structure for the kicker magnet for injection of two electron bunches is 1.2 μs rise time and exponential fall ($e^{-t/\tau}$) with decay constants $\tau < 150$ ns. To generate such pulse magnetic field, the kicker must have frequency response is better than 5 MHz. Therefore, Ni-Zn ferrite foreseen to develop a fast decay magnet.

For efficient magnet operation, some important magnet design parameters and their role in kicker operation are described below:

i) Ferrite materials must have high μQf product at 100 mT, low remanence and low loss magnetic characteristics
ii) Cut-off frequency of magnet must be at least five times apart from working frequency. From harmonic analysis of kicking pulse (1.2 μs sine wave rise and exponential fall with decay constant < 150 ns), the highest harmonic frequency is comes to be 5 MHz. To avoid undesirable effects due to pulse frequencies, Ni-Zn Ferrite should have frequency response better than 5 MHz.
iii) High Pulse Permeability (>1000) provides a minimum return path reluctance of a given section of kicker magnet yoke.
iv) The complex permeability should be constant $\mu^* = \mu' - j\mu''$ over kicker's operation and harmonic content of the kicking pulse. This minimizes the effect of permeability variation in ferrite yoke circuit section and effectively homogenizes the field in kicker aperture.

### *Magnetic Layout*

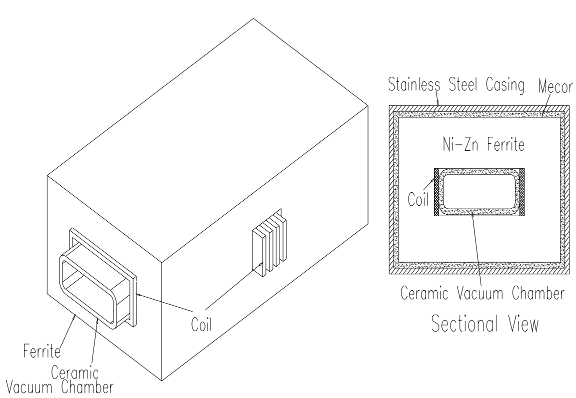


Figure 2: Sectional view of the kicker magnet

Window frame type configuration is chosen on the basis of good field spatial homogeneity, low circuit leakages, and simplicity construction and easy setting over the ceramic chamber as magnet is outside the vacuum. Keeping magnet outside the vacuum, no alignment problems, no electrical feed through, easy maintenance. Electrically lumped type magnet is preferred to meet rise time and fast decay requirement and power supply to keep driving voltage below 30 KV. Magnet layout is shown in figure 2.

### *Magnetic Design*

The conceptual design of the kicker magnet is described in the design review [3]. Magnet is a ferrite window-frame with copper conductor on each side. The aperture (80 X 25 mm) is fixed by the vacuum chamber size. The yoke is made of Ni-Zn Ferrite blocks. It's magnetic properties under pulse conditions have been tested using pulse core tester in built at CAT. Magnetic Simulations has been analyzed using a FEA – FLUX-2D (cedrat), transient field.

Ferrite designed parameters for kicker circuit is shown in Table 2:

Table 2: Ferrite designed parameters

| | | |
|---|---|---|
| 1. | Field inside ferrite | 0.1 Tesla |
| 2. | Ferrite Thickness | 40 mm |
| 3. | Current Amplitude | 2500 Ampere |
| 4. | Average ohmic Losses within conductor | 800 μW |
| 5. | Ferrite Core Loss | 1 Watt |
| 6. | Average Pulse Power Loss | ~ 80 μW |

Over temperature calculations: without any forced cooling the transfer of heat takes place via convection and radiation with temperature difference. For $\Delta T = 10°C$, the power allowed to be dissipated would be 1.8 watts. The pulse power dissipated in the kicker circuit would be 20 μW, which is negligible. Therefore, no cooling is required [5].

## CONSTRUCTIONAL DETAILS

Fast decay magnet is electrically lumped type with a window aperture. The magnet has been constructed in window frame over ceramic chamber using Ni-Zn Ferrite blocks. Their assembly details are shown in Figure 3.

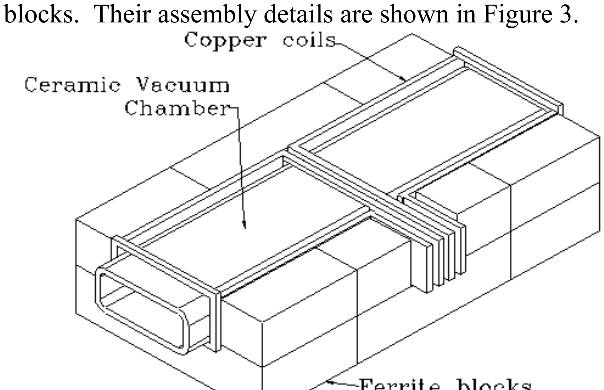


Figure 3: Assembly of Kicker Magnet

### *Ferrite Yoke*

Magnet yoke is made of Ni-Zn Ferrite blocks. They have been cut with precision saw for inserting copper conductors insulated from the yoke with self adhesive kepton.

### *Copper Coils*

Two half turn coils are made from OFHC copper. Coil is silver plated to improve conductivity. The two halves of magnet positioned over ceramic chamber there by giving an accurate mechanical centre.

### *Vacuum Chamber*

Magnet is kept outside vacuum chamber which have made from 97.5 % Alumina (Fritac). The inside section of chamber is coated with a Titanium 4 μm metallic layer to prevent eddy current screening the field inside. Titanium thickness chosen thicker than the skin depth of the particle signal, to keep the beam wall currents unaffected. Low heating is foreseen, and natural cooling through the surrounding air and supporting structure.

### *Pulse Power*

The splitting of single turn in to two half in such a way that magnetic flux of each half turn does not couple with each other to a large extent and inductance of each turn is nearly half of the single turn. Since each half turn inductance of 0.4 μH, it has a time constant of 32 ns (terminated with 12.5 ohms). Two half turns are connected in parallel. The current fed into the conductor through a coaxial ceramic insulated feed through on one side of vessel. The pulse power supply (a low impedance type PFN) is mounted immediately to feed through to minimize the inductance of conductors between kicker magnet and P/S.

## MAGNET PERFORMANCE AND CONCLUSIONS

Using an Integrated Coil and the Probe Coil has carried out pulsed magnetic field measurements for field homogeneity and linearity in magnet aperture. A pulse magnetic field wave forms are shown in figure 4.

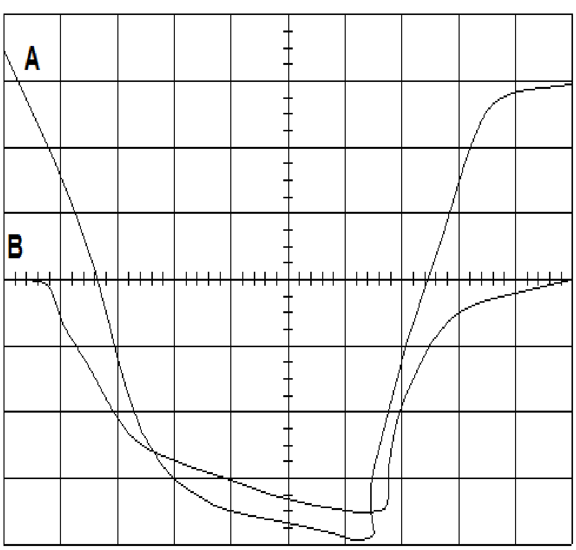


Figure 4: Pulse Magnetic Field Waveforms
Trace - A: Pulse Current at 2500 A
Trace - B: Pulse Magnetic Field, $B_{pk}$ curve

The observed rise time was 1.2 μs (0-100%), which is within acceptance value, fall decay with constant 125-130 ns has been observed. The field quality (ΔB/B) ~ 1 x $10^{-3}$ has been achieved over magnet aperture of 80 mm (H) x 25 mm (V).

The magnet operated at 30 KV at 2500 Ampere and now in routine accelerator operation for injection of 450 MeV electron beam into Indus-1 storage ring. No major problems have been noticed since its installation. Kicker system shows an excellent performance by injecting two electron bunches into Indus-1.

The Fast decay magnet system showed the desired stability, reliability and field homogeneity. The system has been working satisfactorily during storage ring operation since four years and found most efficient, less maintenance and reliable [6].

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