STUDIES OF PROTOTYPE TRANSMISSION LINE EXTRACTION KICKER MAGNET FOR BOOSTER SYNCHROTRON

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Abstract
Existing lumped type extraction kicker magnet has limitation of generating fast rise magnetic field waveform. Two out of three e bunches (66 %) are only extracted from Booster synchrotron. For efficient injection into Indus-2, a kicker magnet system with rise time (~ 20-25 ns) & longer flattop (~ 75 ns) with stability of 0.1% is required. To meet these requirements, a multi-cell transmission line kicker magnet development has been undertaken. A 5-Ferrite cell module has been developed for design studies of kicking pulse transmission through ferrite. This paper presents a 3D electromagnetic modeling of a transmission line kicker magnet, Spice time domain analysis & fabrication of a 5-cell module. The results of the study and the methodology used to obtain them are also discussed

INTRODUCTION

Existing fast extraction kicker magnet in Booster synchrotron is lumped type having 45 ns rise time & 60 ns flat top with nearly 1 % stability. Only two out of three electron-bunches are extracted from Booster. For extraction of three electron bunches, kicker must have fast rise time (< 30 ns) & minimum flat-top of 75 ns. Lumped type magnet present a transient mismatch to the pulse power supply, Therefore, it is not possible to achieve fast rise time, long flat-top & stability of 0.1 %.The high performance of fast extraction kicker magnet is crucial for the efficiency of electron beam extraction. To meet requirement of fast rise time of 20-25 ns, flat top of 75 ns & stability of 0.1 % for extraction of three electrons-bunches, it is proposed to use transmission line magnet in which series inductance is divided into discrete ferrite cells sandwiched between plates, which are capacitively coupled to the return conductor. This is perfectly matched system. However, a transmission line kicker magnet is mechanically complex & therefore more difficult & expensive to assemble than lumped kicker magnet

TRANSMISSION LINE KICKER MAGNET

To extract all three bunches from the booster synchrotron or in other words to get 100 % extraction efficiency, an extraction kicker magnet is needed having rise time faster than 32 ns.Transmission line type kicker magnet has been adopted in which whole magnet is designed in the cellular form to get an equivalent to transmission line. With that, the inductance of cell gets reduced which will result in reduced/faster rise time. This is also known as traveling wave kicker magnet as wave propagation takes place in TL.kicker magnet like a wave travels in a transmission line.Window type, electrically lumped kicker magnets are chosen to meet fast response and power supply simplicity. Magnetic design simulations of kicker magnets have been carried out using a FEA package- Flux 2D. The dimensions have been optimized to minimize time dependent reluctance drop in the ferrite yoke, to maximize the flux penetration into the ferrite and kicker operates below the knee of magnetization of B (H) curve (linear region). Each magnet has been constructed in window frame using Ni-Zn ferrite

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CONSTRUCTION

The rise time of lumped kicker magnet is limited by its inductance and stray inductance. And the inductance of the magnet is mainly due to air gap between the poles through which electron-beam passes. That is why the inductance of the lumped kicker magnet cannot be further reduced. This difficulty is solved in transmission line type kicker. The kicker magnet is split into several ferrite cell of low inductance and each cell is connected to ground by decoupling capacitor. Thus ferrites cells are equivalent to the inductors. The decoupling capacitors are realized by interleaving the HV and ground plates. Ferrite yoke is sandwiched between two HV plates .This forms a PFN of characteristic impedance Z0 = _ (L/C). Where L= unit cell inductance, C = unit cell capacitance.The propagation time of current pulse from entrance of magnet to exit of magnet through cells t = n×_ (LC). Where n = number of cells. Therefore TL magnet performs much faster than lumped magnets. Construction of the transmission line type kicker magnet is shown in 1

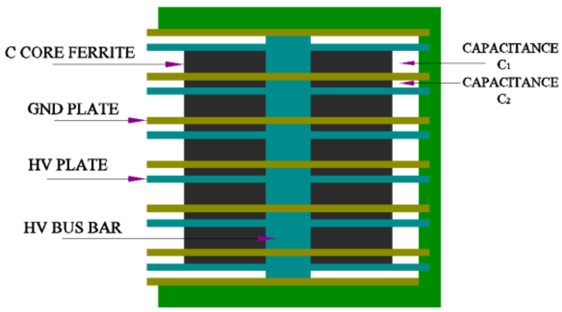

Figure 1: Transmission line kicker cell

P-SPICE SIMULATION

Time domain modeling of Tr line kicker module for its pulse response has been carried out using OrCAD software. Transient solver has been used for the optimization of fast rise, flat top & propgation time thru ferrite cell.The equivalent circuit of the transmission line kicker shown in figure 2. Pspice modeling of kicker module has been performed for unit cell inductance & kicking pulse propagation.

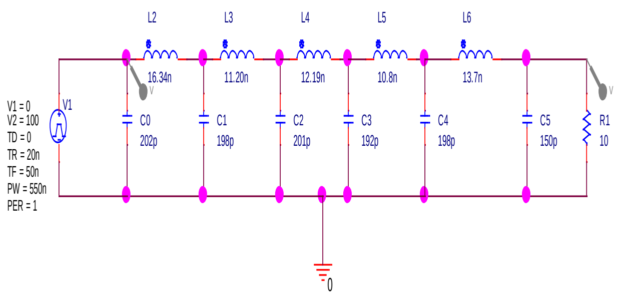

Figure 2: Equivalent circuit of 5 cell TL kicker Module

For simulation purpose prototyping magnet is excited with step input pulse with rise time 20 ns and flat-top 100 ns, Magnetic field in the TL kicker magnet builds up progressively as shown in figure 3.

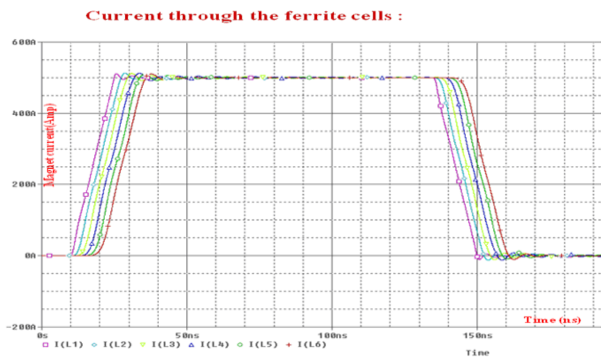

Figure 3: Simulated response of 5 cell kicker module

PROTOTYPE MODULE

We have developed a 5 cell TL kicker module it consists of five C-core Ni-Zn-Co ferrite sandwiched between two HV conductor plates. There are 6 HV plates & 7 Grounds plates each are connected by HV bus bar and GND bus bar respectively. The equivalent circuit of the 5-cell kicker magnet consisting of series inductances and parallel capacitors is equivalent to transmission line of 10 ohm characteristic impedance.

When a magnet is fabricated in cellular form with all cells quite uniform, then also it is observed that inductance of all the cells in not same. Reason for this is that the inductances of adjacent cells are mutually coupled together: a central cell is mutually coupled to a cell on either side, whereas an end cell is mutually coupled to only one other cell. In reality the situation is more complex than this because even the second cell from each end of the kicker magnet has a slightly increased inductance compared with the central cells. To incorporate this into the model the mutual inductance between 2 cells, separated by one cell, also has to be considered. Remembering that, during steady-state, the current is the same magnitude and in the same direction in all cells:

Le =Ls1 + k12 (Ls1 Ls2) +k13 (Ls1 Ls3)**, where**

Le is the total apparent series inductance of the end cell and Ls1, Ls2, and Ls3 are self inductances of three cells: Ls2 is sandwiched between Ls1 and Ls3. Since all cells are nominally identical, then Ls1 =Ls2 =Ls3 .k12 is the mutual coupling coefficient between Ls1 and Ls2; k13 is the mutual coupling coefficient between Ls1 and Ls3.

For a central cell, of self inductance Ls1, the total series inductance of this cell, Lc, is given by:

Lc =Ls1 + 2k12 (Ls1 Ls2) + 2k13 (Ls1 Ls3) for the second cell from the end of the magnet cell the total apparent series inductance of this cell, Le2, is given by:

Le2 =Ls1 + 2k12 (Ls1 Ls2) +k13 (Ls1 Ls3)

MEASUREMENTS

Mutual inductances have been measured using LCR meter. Excellent agreements between measured & calculated values have been observed. Measured pulse response with rise time of about 12 ns of Tr kicker module is shown in figure 4.

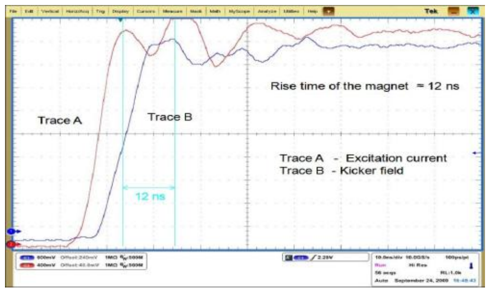

Figure 4: Measured pulse response of Prototype Tr kicker module

Measured per cell inductance & capacitance of the kicker module is 12.56 nH & 8.22 pF respectively. We observed good agreement between analytical and simulated results. These studies enable us optimum design of actual transmission line kicker magnet.

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REFERENCES

1. R.S.Shinde, etal Technical Note: Studies of Prototype Transmission line kicker magnet", March 2009