DESIGN CONCEPT FOR AGS INJECTION KICKER UPGRADE TO 2 GEV*

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Abstract

The present AGS injection kickers at A5 location were designed for 1.5 GeV proton injection. Recent high intensity runs have pushed the transfer kinetic energy to 1.94 GeV, but with an imperfect matching in transverse phase space. Space charge forces result in both fast and slow beam size growth and beam loss as the size exceeds the AGS aperture. A proposed increase in the AGS injection energy to 2 GeV with adequate kick strength would greatly reduce the beam losses making it possible increase the intensity from 70 TP ($70*10^{12}$ protons/s) to 100 TP. R&D studies are being undertaken by TRIUMF, in collaboration with BNL, to design two new kicker magnets for the AGS A10 location which will provide an additional deflection of 1.5 mrad for 2 GeV protons. TRIUMF has proposed a design for a 12.5 Ω transmission line kicker magnet with rise and fall times of 100 ns, 3% to 97%, and kick strength uniformity for protons of ±3% over 90% of the aperture, powered by matched 12.5 Ω pulse-forming lines. This paper describes the present status of a prototype design including the results of detailed 2D and 3D electromagnetic modelling of a transmission line kicker magnet and PSpice time domain analysis of the magnetic kick strength.

INTRODUCTION

Table 1:Existing A5 and proposed A10 kicker parameters.

Parameter	Existing A5	Proposed A10
Proton energy	2.0 GeV	2.0 GeV
Deflection angle	2.48 mrad	1.5 mrad
Gap height	57.15 mm	81 mm
Gap width	127 mm	137 mm
Rise time 3 to 97%	140 ns	100 ns
Fall time 97% to 3%	140 ns	100 ns
Flat-top Duration	0 to 2250 ns	0 to 1650 ns
Pulse Repetition	7.5 Hz	7.5 Hz
Number of magnets	3	2
Total magnet length	0.953 m	0.66 m
Magnetic field	24.2 mT	19.1 mT
Current	1100 A	1235 A
PFN Voltage	32.5 kV	30.9 kV
Magnet type	lumped	transmission line

Three existing lumped inductance A5 injection kickers were designed for 1.5 GeV proton injection. Adding two kickers, located in the A10 section, approximately 17 m downstream of A5, will increase the total beam deflection (Table 1).

MAGNET DESIGN AND CONSTRUCTION

General

A carefully matched high bandwidth system is needed to obtain the stringent pulse response requirements. Hence each of the two A10 systems is composed of a Pulse Forming Line (PFL) and an 11 cell travelling wave kicker magnet, connected by a matched transmission line and terminated by a matched resistor. To obtain a compact and cost efficient design a low system impedance (Z) of 12.5 Ω is chosen. Fig 1 gives the basic circuit diagram.
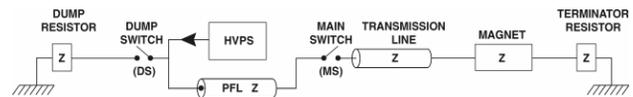

Figure 1: Schematic circuit of system.

The PFL nominal operating voltage is 31 kV. BNL requires that the system be tested at 50% above its nominal voltage, i.e. 46.5 kV. A design voltage of 50 kV allows the use of several proven components such as transmission line, connectors and terminator resistors [1].
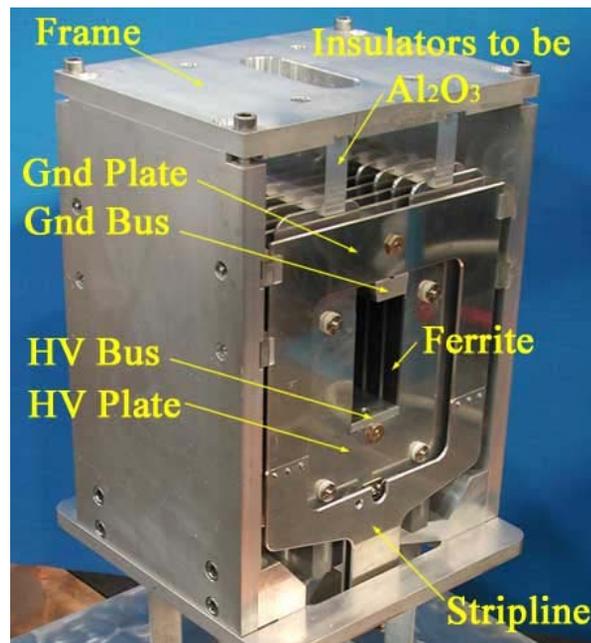
Construction

Figure 2: Prototype TRIUMF Kicker Magnet.

The proposed design for the AGS A10, 11 cell, transmission line kicker, is based on a TRIUMF prototype 10 cell kicker [2, 3] (Fig 2), which was based on designs originated at CERN [4]. The A10 kickers will be fabricated using 304L Stainless Steel. This is due to requirements of both vacuum (the AGS vacuum is

typically in the range 10^{-7} Torr to 10^{-9} Torr) and bake out at 200°C. The transmission line type kicker consists of ferrite C-core sections sandwiched between high voltage capacitance plates. One C-core, together with its ground and high voltage capacitance plates, is termed a cell. Each cell conceptually begins and ends in the middle of the HV capacitance plates.

The 11 cell A10 kicker has two main stainless steel conductors: a high voltage (HV) busbar and a ground (GND) busbar. The HV busbar interconnects twelve HV capacitance plates, and the GND busbar interconnects thirteen GND plates. The injected AGS proton beam will travel through the aperture and encounter magnetic and electric fields. Careful design of the mechanical components (distances and radii) aims to maintain the maximum electrical field below 5 kV/mm[8].

Kicker Magnet Impedance

The characteristic impedance is given by $Z = \sqrt{L/C}$, where L and C are the inductance and capacitance per cell of the kicker magnet, respectively. Reflections cause field ripple and potentially reduce the life of the thyratron switches. In order to avoid impedance mismatches, and therefore reflections, the impedance of the kicker magnet must closely match the impedance of the system. The total series inductance of a central cell is determined by the aperture dimensions and can reasonably accurately be calculated from the equation: $L = \mu_0 \times w \times l / h$, (63.89 nH) where, w is the width of the aperture (137 mm for optimized aperture), l is the length of a cell (30.06 mm), and h is the height of the aperture (81 mm). However, since the legs of the ferrite are profiled (Fig 3) to improve the deflection uniformity, it is necessary to use a code such as Opera2D [5] to accurately calculate the total series inductance of a cell: simulations give 62.36 nH per central cell. Thus, to achieve a 12.5 Ω kicker magnet, the nominal cell capacitance is 399.1 pF.

The capacitance of a cell is made up of several terms including parallel plate capacitance between the HV and GND plates, and edge effects between the sides of the HV plates and both the GND plates as well as the magnet frame. To achieve the 399 pF capacitance with a high degree of accuracy several cells of the kicker magnet have been simulated [6] with the 3D electromagnetic software Coulomb [7]. In order to validate Coulomb, the software was used to model the prototype TRIUMF kicker magnet and the predicted capacitance was compared with measurements [8].

Deflection Uniformity

The specifications for the AGS A10 kicker magnet require an aperture width (the distance between the adjacent surfaces of the HV busbar and the GND busbar) of 127 mm, and an aperture height (the distance between the inner surfaces of the legs of the C-core ferrite) of 81 mm. However 2D electromagnetic simulations carried out to optimize field uniformity[12] within the AGS A10 aperture resulted in the following (Fig 3):

- Increasing the aperture width to 137 mm;
- Shaping of the aperture side surface of the GND busbar (this surface of the GND busbar was flat for the prototype TRIUMF kicker magnet);
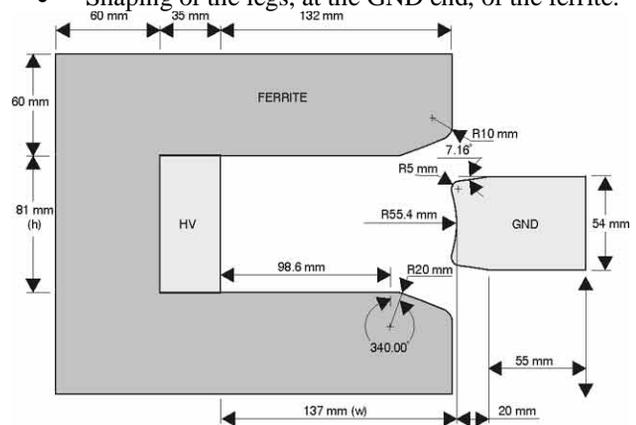- Shaping of the legs, at the GND end, of the ferrite.

Figure 3: Cross section of optimized aperture.

The total deflection angle is obtained from the vector addition of the deflection attributable to the horizontal magnetic field and the vertical electric field. The magnetic and electric components of deflection are arranged to be added for the optimized geometry, giving the most uniform deflection. Fig 4 shows a contour plot of the resultant total deflection for protons, normalized to the deflection at the centre of the aperture. The uniformity is within ±1% over 85% of the aperture area and within ±2.1% over 90% of the aperture area. Since β is smaller for Au^{77+} ions than for protons, the electric field kick is larger for Au than for protons: for Au^{77+} the uniformity is within ±3% over 80% of the aperture area.
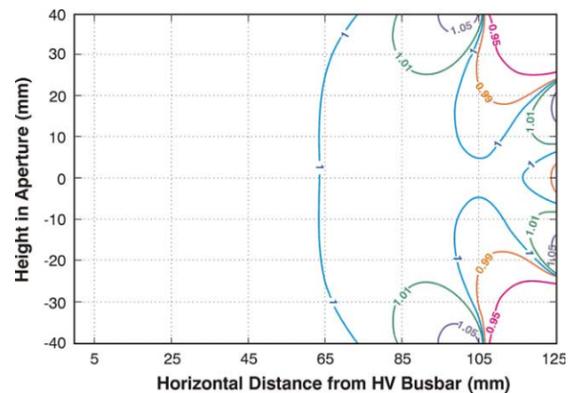

Figure 4: Normalized contour plot of $\theta_x = \theta_{B,x} + \theta_{E,y}$, for protons for the optimized geometry.

Similar deflection uniformity could also be achieved without having to profile the end of the legs of the ferrite or the ground busbar. However the separation of the GND and HV busbars would need to be 147 mm resulting in a predicted inductance of 68.9 nH/cell, 10.5% greater than the geometry of Fig 3. Hence, to achieve 12.5 Ω impedance, the nominal cell capacitance would need to be increased by 10.5%, therefore increasing the size and cost of the kicker as well as the cell transit time.($\sqrt{L \times C}$)

PSpice Modelling

The electrical circuit of the kicker system, including PFL, thyratrons, transmission line, kicker magnet and terminators has been optimised using PSpice [8]. The model of the thyratrons is based on a previous model, which includes displacement current [9], but has been modified to simulate the decay of the plasma density at the end of the current pulse. The plasma density drops with a time constant in the region of 2 µs to 7 µs [10]: analysis of previous measurements [11] show a time constant of 5 µs for a CX2003, 3 stage, thyratron: the 5 µs is used in the revised model.
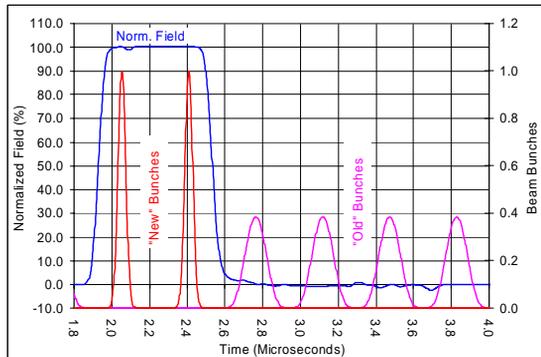

Figure 5: Predicted Field Pulse, and simulated "Beam Bunches" for 2 bunches per transfer.

Measurements and simulations for the prototype TRIUMF kicker [3] show the validity of using Opera3D, to calculate the inductance of all the cells of a kicker, including fringe fields at the ends. The same procedure has been applied to the AGS A10 kicker magnets and the calculated cell inductance has been included in a revised mathematical model of the kicker magnet: the detailed results, and the revised model, will be presented at MT19.

The PSpice model also includes dispersion in the PFLs and the transmission cables: the frequency dependent dispersion characteristics have been fitted to the cable manufacturers data sheets. The simulations include a representation of the beam bunches, to allow optimization of the field. The next-to-last bunches and bunches previously transferred into the AGS ring are diluted on the AGS injection porch: these are referred to here as "Old" beam bunches. "New" beam bunches are those that have recently been transferred from the AGS Booster. Fig 5 shows the predicted kicker field pulse, as well as the representation of the beam bunches, for the transfer of 2 bunches from the Booster to AGS ring per injection cycle. The effect of the length of the transmission cable between the PFL and the kicker magnets has been studied, within constraints of the site (250 feet minimum from PFL to kicker), to minimize the deflection of "old" bunches due to post pulse ripple. The predicted 3% to 97% rise time is 97 ns, which is within the specified 100 ns.

SUMMARY

A design has been carried out for the proposed AGS A10 kicker system. The aperture of the kicker magnet has been optimized to achieve the required beam deflection uniformity, for proton transfer, while minimizing cell inductance. The plate geometry to achieve the cell capacitance has been selected based on detailed 3D electromagnetic simulations: the software has been validated against measurements on a transmission line kicker magnet. The kicker impedance is expected to be correct and hence is not designed to be adjustable. PSpice time domain analysis of the magnetic kick strength has been carried out to optimize the overall system.

ACKNOWLEDGEMENT

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