Development of a Modular and Upgradeable Fast Kicker Magnet System for the Duke Storage Ring*

R. J. Sachtschale, C. Dickey, P. Morcombe
Duke University, Free Electron Laser Laboratory
Box 90319 Durham, NC 27708-0319

Abstract

A cost effective injection kicker has been developed for the electron storage ring at Duke. Magnet components and driver circuitry are integrated in a modular format that has resulted in a low cost, highly maintainable and upgradeable development system. The driver and magnet can be easily reconfigured from a simple LRC circuit(parallel or series) that provides a pulse approximating a half sinusoid to one utilizing a pulse forming line to provide a more trapezoidal pulse shape. The modular development platform has permitted the kicker to evolve with the storage ring in a way that minimizes further expenditures of time and materials.

I. Introduction

The injection kicker for the Duke Storage Ring is a basic split frame magnet. The magnet is split along a longitudinal vertical plane, with respect to the electron beam path, essentially forming two C-core magnets. The core material is CMD10 from Ceramic Magnetics Inc., Fairfield, NJ. It is a Ni-Zn ferrite chosen for it's high saturation flux density and very high curie point. The magnet halves are joined with their open ends facing each other as shown in figure 1.

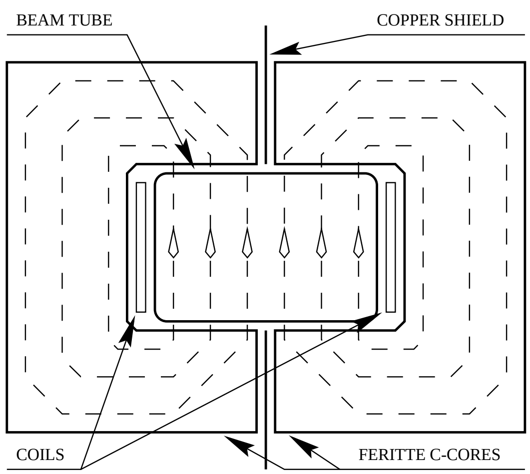

Figure. 1. End View of a Split Frame Magnet

The current coils extend the length of the magnet and are driven with equal but opposite current pulses. This induces an equal but opposite magnetic flux to circulate in each of half of the magnet.

At the interface between the two halves, the opposing flux is forced up through the gap inside the beam tube. This produces a vertical magnetic field in the chromium coated beam tube which is used to *kick* the electrons to the left. The required kick varies from 2.927 mrad for stacking to 5.853 mrad for single bunch injections. If the current pulses to the coils are not equal and opposite, a flux imbalance would allow an unopposed net flux to cross the interface and circulate between the two halves. To prevent the possibility of a net circulating flux, a copper shield is typically placed between the halves.

Although this is a common type of magnet geometry, budget constraints required the following features:

- Reliable and serviceable system that excludes the need for a complete spare backup magnet.
- Driver upgradeable to handle injections from 250 MeV to 1 GeV(integrated field range of 2.44 to 19.51 $kGs * cm$).
- Driver reconfigurable from a 150 ns half sinusoid pulse to a trapezoidal pulse with 350 ns flat-top and $<$ 75 ns rise/fall-times.

A major benefit of a split frame magnet is that it can be removed from the beam tube without disturbing the vacuum system. This feature was exploited to make the most failure prone component serviceable at the beamline. Typically the most failure prone component is the insulation of the magnet coils.

II. Magnet Design

A common mode of failure in kicker magnets is the breakdown of the potting compound. A common potting compound is silicone. Kicker magnets employ one turn coils to minimized inductance resulting in large electrical stress. When combined with ionizing radiation and rf heating, silicones are more prone to damage than other materials like epoxy. However silicones are more easily removed than epoxies when a repair is required. We decided upon a hybrid approach. The magnet was potted in RTV Silicone fron General Electric while the coils were potted as separate disposable assemblies in ceramic filled epoxy.

The potted copper strap that forms the coil is shown in figure 2. Connecting posts are attached to each end. Five layers of kapton film are wrapped around the strap in a spiral fashion between the two posts. It is then placed in a mold and vacuum potted with Stycast 2850ET Ceramic Filled Black Epoxy from Emerson Cumming Inc., Worburn, MA.

The connecting posts of the coils fit into a mating socket in the magnet body. The mating socket is molded into the silicone potting compound that surrounds the ferrite in the copper magnet case. Female bridge formed Louvretac bands from AMP Inc. Harrisburg, PA are used in the mating socket to make circumferential contact with the connecting posts. Final assembly of the magnet can be seen in figure 3.

The coil assembly and mating connections were tested with 1.6kA, 500ns pulses at a rep rate of 10 pps. This test was performed 8 hours per day for five days, resulting in over 1 million

*Supported by the U.S. Air Force Office of Scientific Research, contract F49620-93-1-0590 and the U.S. Army Space & Strategic Defense Command, contract DASG60-89-C-0028.

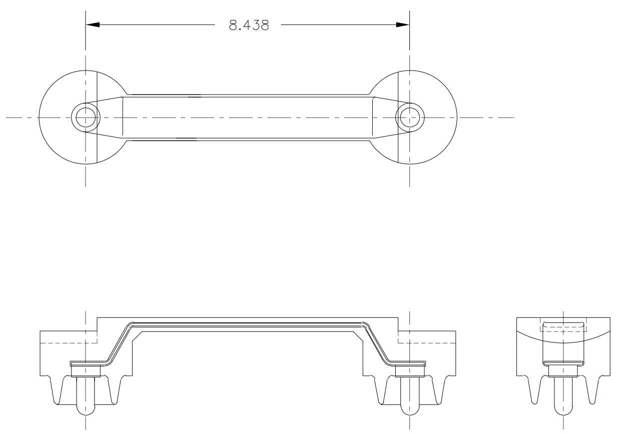

Figure. 2. Magnet Coil Assembly

cycles without any sign of degradation. The same coil assemblies and connectors have been in use since storage ring commissioning began the first week of November '94.

External connections to the magnet are made with 1-5/8" 50Ω coaxial hardline. Flanges that mate to the hardline are built into the magnet case. Since the hardline is pressurized with SF_6, O-rings, held in place by a nylon carrier, are used to keep the SF_6 from leaking out through the magnet.

The complex impedance of the magnet and connecting hardware was measured with a Hewlett-Packard 4194A Impedance Analyzer. The results of these measurements were used to build a simple circuit model. Computer simulations using this model helped to determine the appropriate capacitance and resistance values used in the driver circuit. The schematic of the final circuit is shown in figure 4.

III. Driver Assembly

The driver circuitry is housed in a cylindrical brass vessel. The circuit components are assembled on the bottom plate. The upper half of the vessel(the top plate welded to the 12 inch pipe) is lowered over the assembled components and bolted to the bottom plate. An O-ring in the bottom plate and a 12 hole bolt circle provide a seal that allows the interior volume to be pressurized with SF_6. Figure 5 shows the layout of the principle components in the driver assembly. A Maxwell 40184 Spark Gap is used along with a Maxwell 40168 Trigger Generator(not shown). This combination was chosen for its low jitter specification. Omitted from the figure are the spark gap bias resistors, and the blocking capacitors that isolate the driver circuit from the spark gap trigger generator. Maxwell specified components were used.

The disk resistor is a 0.2Ω Carborundum current shunt. A $4.95k\Omega$ resistor is connected from the node of the disk resistor and capacitor bank, to the center of a BNC bulkhead feed-through in the bottom plate. This provides a 100:1 divider into a 50Ω scope channel for monitoring the driver current in the control room. The belleville washers provide the 25psi contact force recommended for the disk resistor. Although this circuit uses a parallel damping resistor, a series damping resistor could be

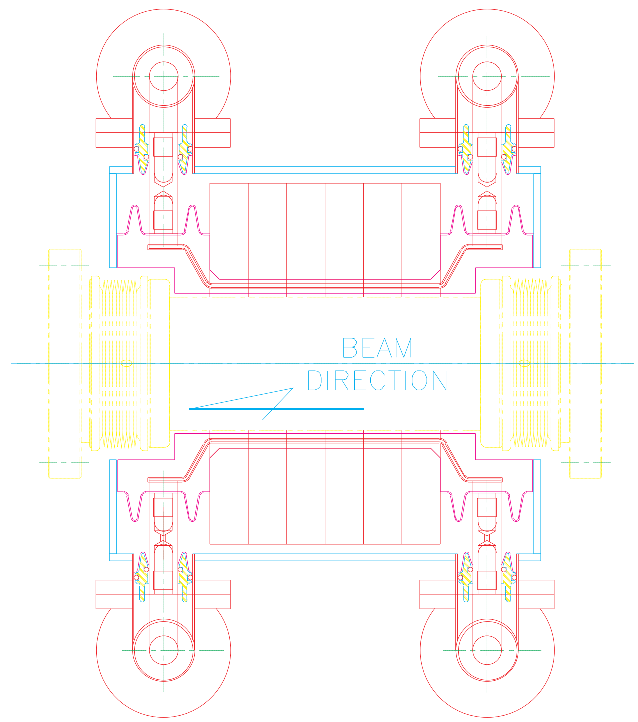

Figure. 3. Top View of Kicker Magnet

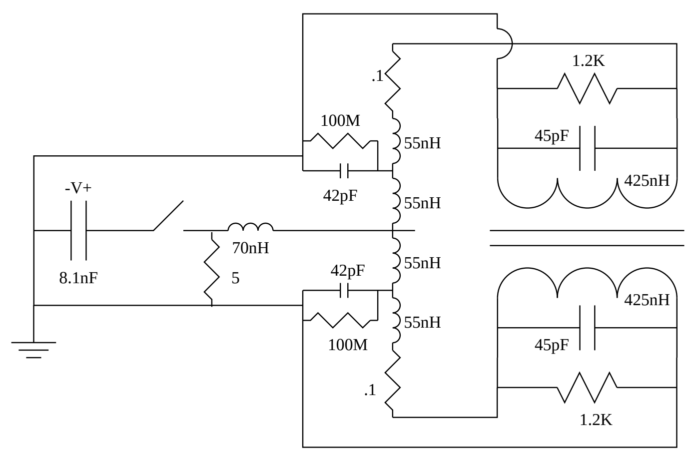

Figure. 4. Schematic of Model Kicker Circuit

employed by increasing the value of the series disk resistor.

1-5/8" coaxial hardline flanges are welded to the top and bottom plates. By using a variety of these standard fittings and modifying them as needed for our applications, a very modular development system unfolded. For instance, original specifications for the kicker pulse required a long flat-top to be provided by a pulse forming line(pfl). The pfl was to be fashioned from four lengths of RG-213, with all eight ends attached to the spark gap switch in place of the capacitor bank. For this a 3-1/8" to 1-5/8" 50Ω taper was modified and attached to the 1-5/8" flange in the bottom plate. A 3-1/8" blind flange was made to mate to the large end of the taper. Holes and cable shears for nine RG-213

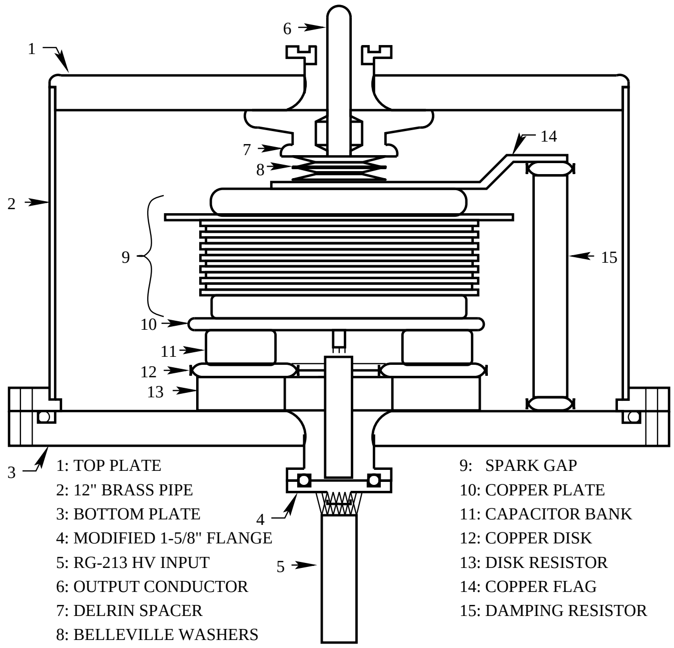

Figure. 5. Driver Housing

cables(8 pfl ends and 1 HV lead) were added to the blind flange. Inside the taper the center conductors attached to a common post similar to the output post at the top of the driver housing. This sort of installation is depicted in figure 6.

To connect the driver to the magnet, the hardline was modified in-house to form an electrical Y connection with one input and two outputs. The input of the Y is connected to the driver circuit. The outputs of the Y are hooked up to opposite ends and opposite sides of the magnet so that the driver current is flowing in opposite directions in the two coils. The other end of each coil is shorted to the magnet case which provides the return path back to the outer conductor of the hardline.

IV. Conclusion

Our modular design approach has provided us with an extremely reliable fast kicker magnet. A variety of adapters have been made during the course of development to provide a system that can be readily reconfigured. The only failure as of the time of this writing has been of the current limiting resistors in the spark gap trigger circuit. These were quickly repaired and their failure was likely due to the kicker being operated without sufficient dielectric gas pressure between the spark gap electrodes. This caused runaway self-triggering of the spark gap and exceeded the average power rating of the current limiting resistors.

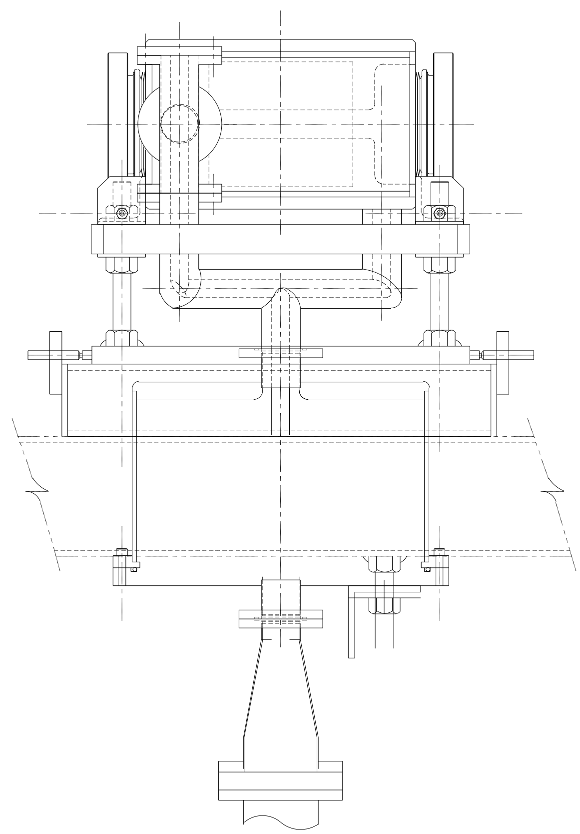

Figure. 6. Installation Side View