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A LOW COUPLING IMPEDANCE DOUBLE HELIX STRUCTURE FOR USE IN A FERRITE KICKER MAGNET*

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Summary

In a machine such as the CBA, the ejection ferrite kicker magnet has a very large longitudinal and transverse coupling impedance which could destroy the beam. Using a double helix structure that surrounds the beam, the beam induced fields are confined within the helix and, therefore, decoupled from the kicker; but at the same time the helix is transparent to the external fields of the kicker. At first, this may seem paradoxial that the helix is opaque to the fields generated inside the structure by the beam and simultaneously transparent to the external fields generated by the kicker.

Introduction

In circular accelerators and in particular storage rings it is important that the beam be shielded by a metal vacuum chamber to prevent the fields of the beam from coupling to any external parasitic impedances. When a device, such as a pick up electrode, RF accelerating gap, etc. is placed around the beam for the purpose of monitoring or reacting on the beam, then the beam, by reciprocity, must also react back on the device. This reaction of the beam is referred to as the beam coupling impedance. Obviously, if the device is to function as intended then the beam cannot be shielded by a metal vacuum chamber.

Certain devices, such as the ejection kicker magnet are essential to the operation of a machine like the Colliding Beam Accelerator (CBA), but the beam coupling impedance is so high that it would cause the beam to blow up. A solution must be found that does not interfere with the operation of the kicker magnet, but at the same time must substantially reduce the beam coupling impedance.

For the case of a ferrite frame ejection kicker magnet,[1] as designed for the CBA, it will be shown that the double helix structure is completely transparent to the kicker magnet fields, i.e., the kicker fields can readily penetrate the double helix structure and act on the beam. It will also be shown that the double helix structure is opaque for the fields of the beam (both TM and TE), thereby substantially reducing the coupling impedance between the beam and the kicker magnet.

It would seem that the properties attributed to the double helix structure are paradoxical, that is reciprocity has been violated. This indeed is not the case, but as will be shown that this unique property of the double helix structure is related to the fact the kicker magnet magnetic field is uniform and perpendicular to the beam line and also to the magnetic fields of the axially symmetrical TM and TE modes that are excited by the beam.

It is necessary that we consider both the longitudinal and tranverse coupling impedances. Measurements of the longitudinal impedance were made using a transmission line, similar to that described by Hahn and Pedersen.[2] The actual system used will be described in a future report. There were no extensive measurements made of the transverse impedances, but some simple checks were made.

Kicker Magnet

Figure 1A shows a short section of the kicker magnet that was used for making measurements. The dimensions of the ferrite are shown in mm; also shown are the conductor bars which energize the magnet as described in reference 1. Figure 1B and C show the magnet field in two different planes. Also shown in Figure 1C is a metal enclosure that completely surrounds the kicker magnet with beam pipes at each end.

It is important to note in Figure 1C that the total flux perpendicular to the +y, +z plane is zero, and likewise in the -y, +z plane. If a wire were placed along the z axis of the cavity and shorted to the end walls of the metal enclosure, no current will flow in the wire. This is true for any wire in the x, z plane.

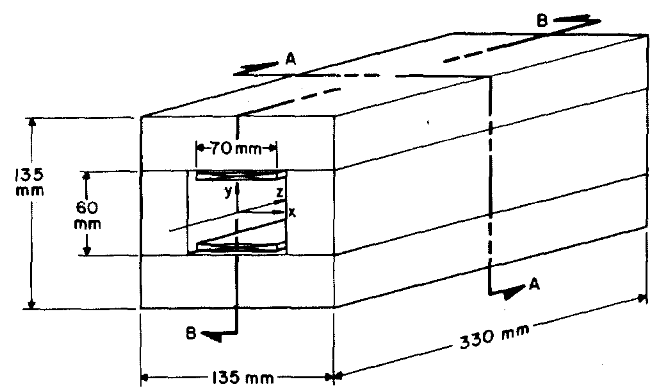

Figure 1A. Ejection Kicker Magnet

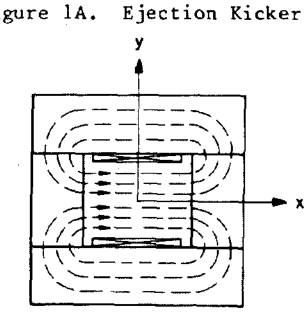

Figure 1B. Section A-A

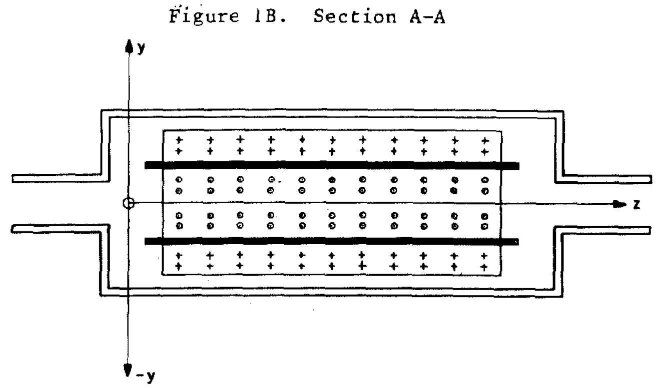

Figure 1C. Section B-B

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Double Helix

The double helix is made up of two oppositely wound spirals of radius r as shown in Figure 2A; the two spirals are then translated into the same coordinate system to form a double helix. The two spirals cross each other at the point $y = \pm r$, and at these points they are shorted together. The projections of the double helix in the x, z and y, z planes are shown in Figure 2B and 2C respectively. In Figure 2C, it should be noted, that each half turn of one helix lies directly above the corresponding half turn of the other helix; that is, alternate half turns of each helix are in each others shadow.

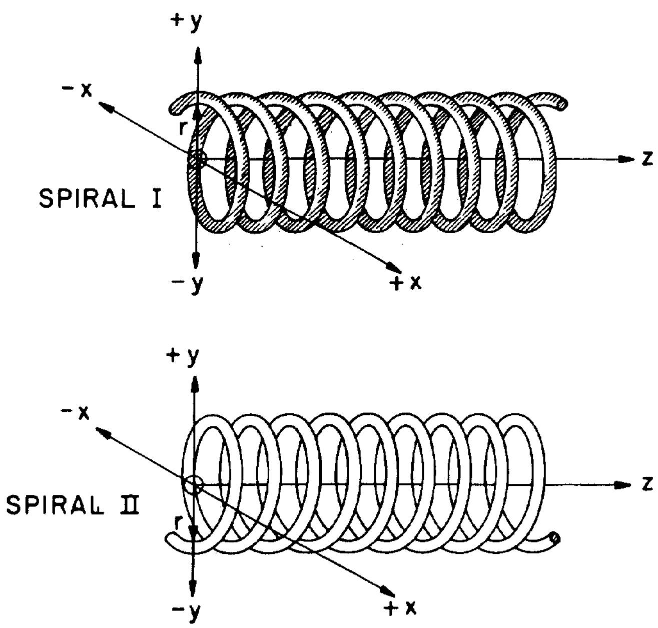

Figure 2A. Oppositely Wound Spirals

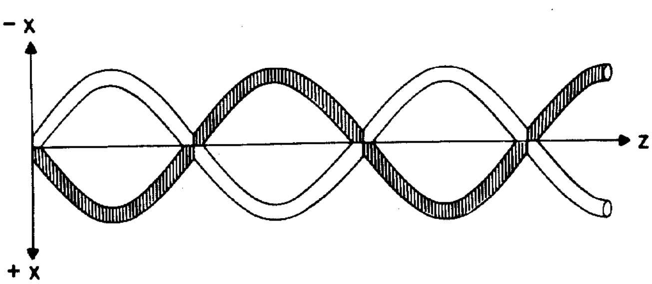

Figure 2B. X,Z Projection of Double Helix

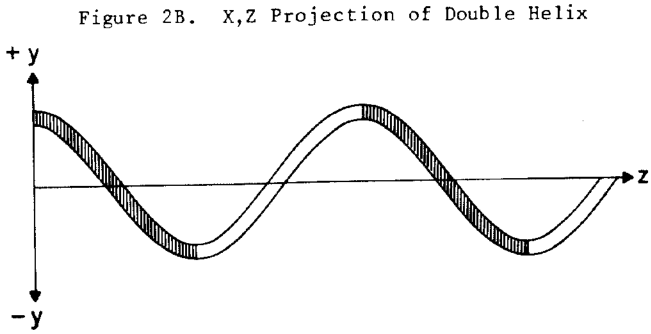

Figure 2C. Y,Z Projection of Double Helix

If we have a magnetic field that is perpendicular to the x, z plane (Fig. 2B), it is obvious that the rise time of the magnetic field will be adversely affected since circulating currents will flow in the projected short circuited loops. For a magnetic field perpendicular to the y, z plane (Fig. 2C) we see that there are no short circuited loops to interfere with the rise time of the magnetic field.

Placing the Double Helix in the Kicker Magnet

The double helix is now placed in the kicker magnet and oriented as shown in Figure 3. The helix must be connected to the metal walls as shown, and the only other requirement being that the helix contain an odd integer number of half turns. The actual number of turns will be determined later.

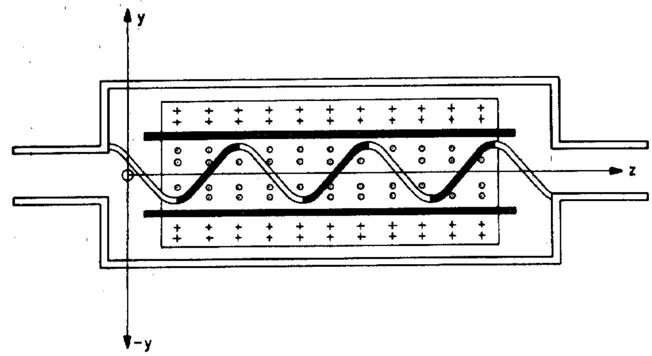

Figure 3. Helix In Kicker Magnet

If we now consider the following two closed loops: the first formed by the helix and upper half of the metal enclosure and the second half formed by the helix and the lower of the metal enclosure, we can easily see that the total magnetic flux perpendicular to the first loop is exactly equal to zero and likewise the total flux in the second loop; consequently, there is no circulating current in the helix.

Tests[1] were performed on a magnet both with and without a double helix and it was found there was no decernable change in the rise time of the magnetic field. The rise time of the field was 0.3. μsec.

The Double Helix as an RF Structure

The question that now must be addressed is, how effective is the helix in shielding the electromagnetic fields of the beam from the ferrite. The beam induces currents in the helix which have both an i_z and i_ϕ component (note: inside the helix we have now changed to cylindrical coordinates). Since the i_z and i_ϕ components of current correspond, respectively, to H_ϕ and H_z components of field, it is now possible for the helix to support both TM and TE modes: corresponding to the longitudinal and transverse coupling impedance.

Figure 4 shows the measured relative longitudinal impedance of the ferrite kicker magnet only. As expected the impedance is quite high. Figure 5 shows the relative impedance for various double helix structures placed inside the ferrite kicker. At first inspection it may seem odd that, the longitudinal coupling impedance in Figure 5 increases as the number of turns increases. This can be readily explained by the fact that the longitudinal coupling impedance of a double helix, is related to its capibility of being able to carry an i_z component of current. As the number of turns are increased, the i_z component of beam induced current decreases; corresponding to an increase in longitudinal impedance.

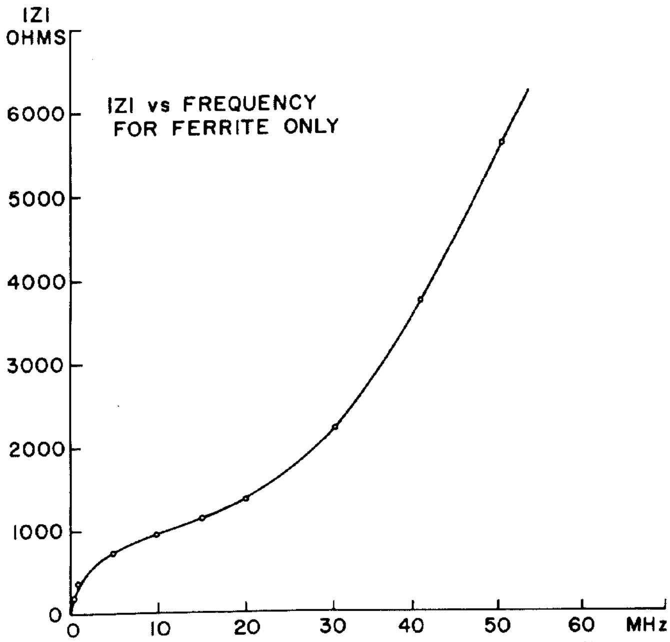

Figure 4. Relative Longitudinal Impedance of Ferrite Kicker

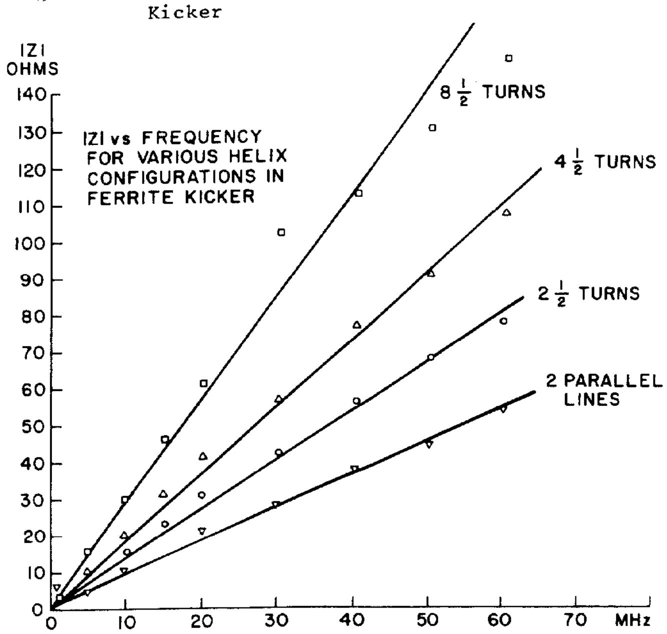

Figure 5. Relative Longitudinal Impedance of Ferrite Kicker with Double Helix

One should not conclude that the fewer the number of turns the better the structure since no consideration has yet been given to the transverse impedance, which is related to the TE modes. To support a TE mode we need an H_z field or i_ϕ component of current on the inside of the helix. The larger the number of turns the greater ability of the double helix to carry an i_ϕ component of current, corresponding to a lower transverse impedance.

As previously noted, the impedance measurements were made using a transmission line. For measuring lumped impedances, the above method gave excellent results of the absolute magnitude of the impedance. For the kicker magnet, where we are dealing with a distributed impedance, there is some question of determining the absolute impedance from the measurements. But, the measurements clearly show that the double helix reduces the impedance of the ferrite kicker by about a factor of 50.

As was noted, no definitive measurements were made for transverse impedance. Some spot checks were made and it was concluded that a reasonable compromise for both the longitudinal and transverse impedances was somewhere between 4-1/2 to 8-1/2 turns for the length of the ferrite kicker shown. Further work is needed to better understand the transverse impedances.

As previously noted, only axially symmetrical modes, as excited by the beam, are considered. An off axis beam would probably experience a higher coupling impedance, but the double helix should still be effective in reducing the impedance. Future work, in this area, is planned.

In the final design the helix will be wound on the inside of a ceramic or pyrex tube. The inside of the tube will be coated with a very thin film of metal. The film should be thin enough to be transparent to all frequencies below 30 to 50 MHz but be thick enough to shield the helix and ferrite above the frequencies. The metal film also serves the purpose of preventing a charge build up on the tube.

Acknowledgement

I would like to thank Louis Mazarakis for assembling the model and making the measurements.

References

1. R.J. Nawrocky, On the Design and Performance of a Prototype of the ISA Ejection Kicker, BNL 31552, Informal Report, June 1982.

2. H. Hahn, F. Pederson, On Coaxial Wire Measurements of the Longitudinal Coupling Impedance, BNL 50870, April 1978.