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A Low Cost, 400 Gauss 18" Gap C-Magnet Using Permanent Magnet Technology

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Abstract

A low cost, low field (400 G) 18" gap C-magnet using permanent magnets has been constructed. This magnet was used in a calibration study in the E799/E832 (KTeV) beamline at Fermilab. The C-magnet configuration was selected for ease of installation around an existing vacuum pipe. An advantage of the permanent magnet design is that no water or power connections are needed.

1 INTRODUCTION

A permanent magnet with 400 gauss central field in an 18 inch gap has been constructed. The magnet is 24 inches long and is in a “C” configuration 28 inches deep. The magnet was built in only a few weeks at minimal cost using available permanent magnet technology from the Fermilab Recycler project [1]. The purpose of this magnet was to separate e^+e^- pairs in order to facilitate a systematic study of the detector parameters in the Fermilab E799/E832 (KTeV) [2] experiment. The details of this measurement are discussed elsewhere [3].

The specifications for this magnet were: a gap larger than 18 inches to fit around a section of non-ferromagnetic 18" OD stainless steel pipe, a field integral of at least 167 gauss-meters or 5 MeV/c perpendicular to the beam covering a region of at least 6" high by 8" wide, a time constraint of 8 weeks from design to completion with a one day installation window, a materials budget of $2k, and minimal manpower resources. A C-magnet design using strontium ferrite permanent magnets was chosen in order to meet these requirements**.**

The “C” design was chosen to enable the installation of the magnet without breaking vacuum or “capturing” a section of vacuum pipe as would have been required for an H-frame design. Permanent magnet technology was used since the expertise and materials were readily available on site from Fermilab’s Anti-Proton Recycler Ring Project. This paper will describe the design, fabrication, and performance of the magnet.

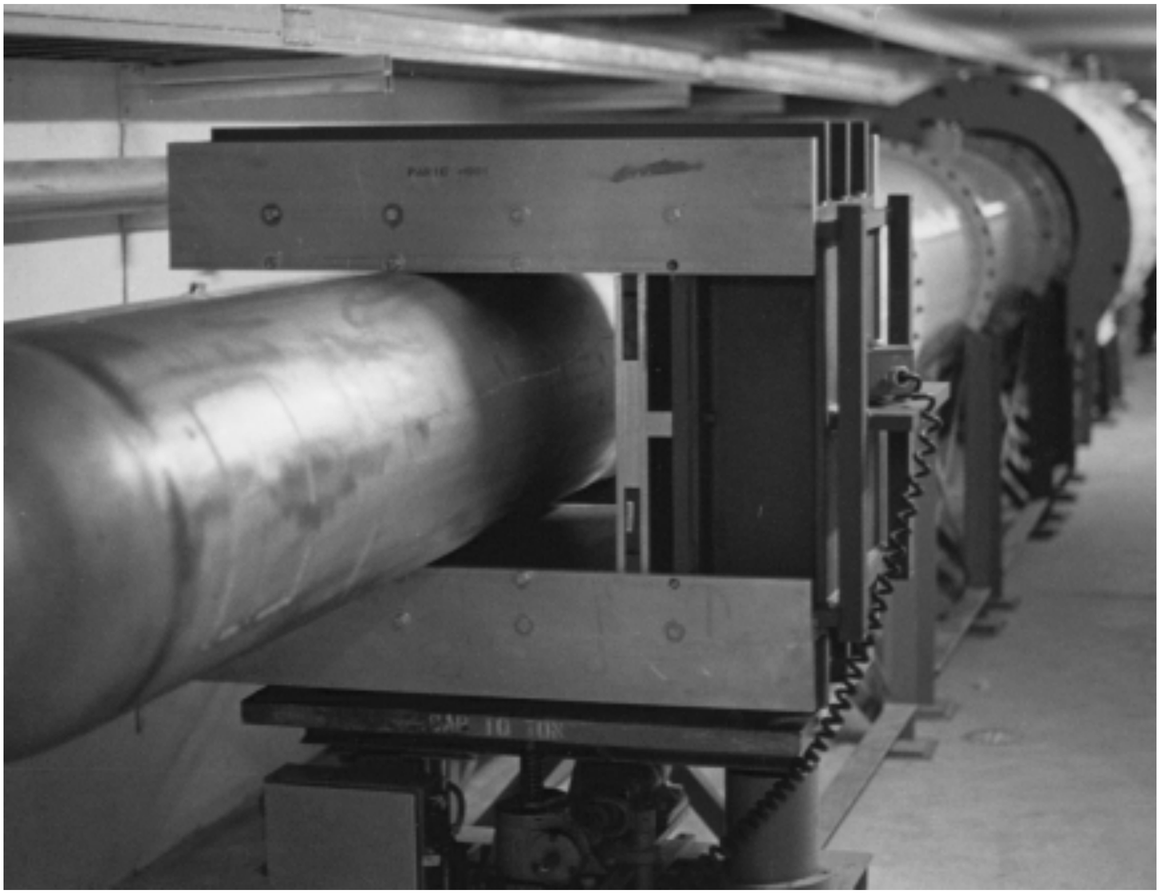

Fig. 1. *Photograph of C-magnet installed in the KTeV beamline. An electric die-cart was used to adjust the elevation*

2 DESIGN & FABRICATION

The magnet was designed using POISSON/PANDIRA for the permanent magnet field calculations [4], and a CAD system was used for the mechanical design.

2.1 Ferrite

Over the past three years extensive experience in the use and building of permanent magnets has been gained in the Recycler Ring project at Fermilab. Dipoles, quadrupoles, and other correction magnets have all been fabricated using strontium ferrite to produce the magnetic field. Strontium ferrite (SrO nFe_2O_3) is an inexpensive, readily available material. For a typical grade 8 ceramic H_c is between 2.8 and 3.4 kOe and B_r is 0.38 to 0.41 Tesla. Over 60,000 ferrite bricks manufactured by Hitachi Metals, of Edmore, Michigan are used in the Recycler project. The magnetic bricks used in both the Recycler project and in this C-magnet are 4" x 6" x 1" with the field oriented so that **B** is parallel to the 1" dimension.

2.2 Field Modeling

The design of the magnet was modeled using PANDIRA, a part of the POISSON/SUPERFISH© package supported by the Los Alamos Beams Division [4]. PANDIRA is a two dimensional model which also calculates forces on the poles**.**

The arrangement selected consisted of a double layer of magnetic bricks for the upper and lower poles, and a pair of single layer sets of bricks on the yoke side of the magnet for field shaping. To reduce the edge effects of the open side of the yoke, the poles were extended an extra 4" on the open side of the “C”. The length of the magnet was chosen as 24" — a multiple of the magnet brick size. Experience [5] suggested that the accuracy of the field predictions for the designs using strontium ferrite bricks should not be expected to be better than about 20%. Further, as two dimensional magnet modeling was being used, the effective length of the magnet could be only roughly estimated. Therefore, the field was designed to be higher than needed in order to be conservative.

The central field as calculated using PANDIRA was 351 gauss. Taking the effective length of the magnet as the physical length of 24", the expected field integral is 6.4 MeV/c or 214 gauss-meters.

2.3 Mechanical Design

Mechanical design of the magnet was driven by four primary goals: 1) provide a design that allows rapid fabrication, 2) provide maximum ease of assembly, 3) sufficiently control the deflections so as to maintain field uniformity, and 4) minimize cost. Initial member sizes considered for various components were limited to the material sizes readily available. Consequently, the member sizes have not been optimized in a manner appropriate for a production run of several magnets.

The mechanical structure consists of the pole pieces and the yoke. The top, side, and bottom sections of the yoke provide the mechanical support and the flux return. The top and bottom yoke sections consist of a 1" thick steel plate, which is the primary flux return, and ribs which provide structural rigidity.

The pole pieces are 1" thick which is adequate to smooth small variations in the field due to differences in magnetization between bricks. The side yoke steel and the shaping bricks (see Figure 2), control the shape of the field near the side of the yoke. This helps reduce the size of the magnet while maintaining the required field uniformity.

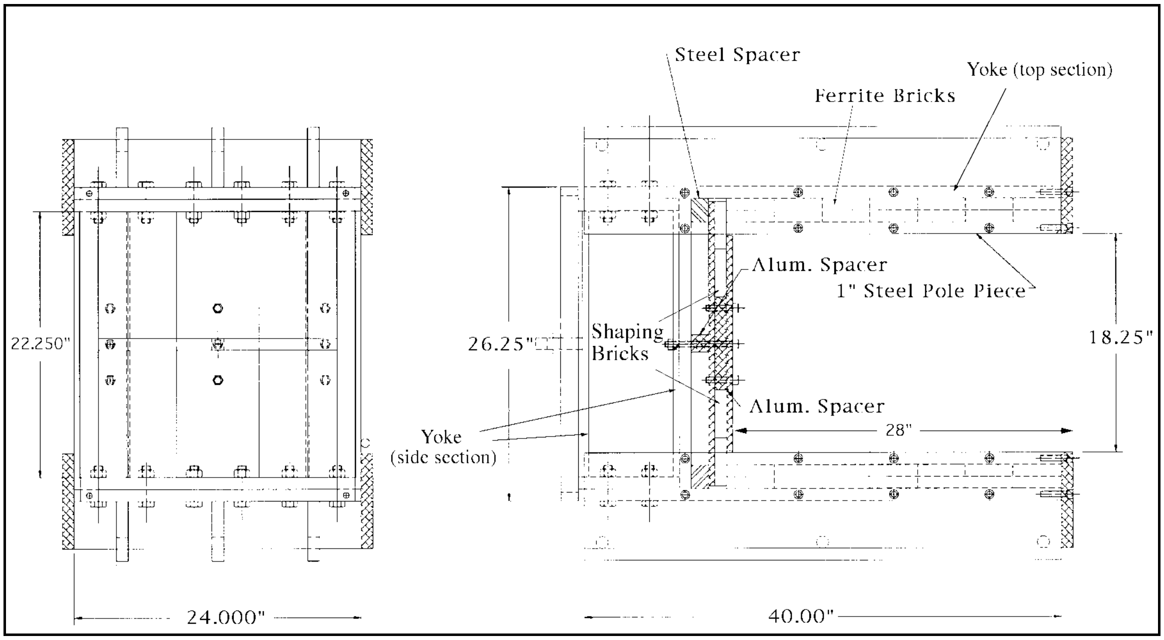

Fig. 2. *Front and side view with dimensions.*

2.4 Fabrication and Assembly

The magnet pole pieces and return yokes were fabricated using A-36 carbon steel. The pole pieces were ground to a flatness of 0.005 inches over the entire surface. Pairs of bricks were glued together using Loctite® Depend. A total of 28 pairs of ferrite bricks were then glued to each pole piece. The bricks were glued to the plate to overcome the natural repulsion and ensure tight packing. Simple aluminum tooling and clamps held the bricks in place while the glue cured for the two to five minutes required for the glue to set.

The top and bottom sections of the yoke were then lowered onto the bricks and pole piece assembly. They were attached to the pole pieces with 1" thick aluminum side plates. Because the bricks were mechanically locked in place, the magnet did not depend on glue for holding the bricks in place for the long term. In a similar manner, side bricks were then attached to the side flux return and the bricks were trapped in place with aluminum plates.

An aluminum pole piece spacer was fabricated as an assembly tool. The top and bottom pole pieces were clamped to either side of this spacer assembly. The side yoke section was then set into place. To ensure a good magnetic flux circuit the mechanical tolerance were kept as tight as possible — typically a few thousandths of an inch.

The magnet was then rotated into position with the magnetic field oriented in the vertical direction. The magnet is up-down symmetric, so the ‘polarity’ was determined at the time of fabrication. After fabrication, the polarity can only be changed by flipping the magnet.

The magnet was fabricated and assembled in 4 weeks using available steel plates and reject permanent magnets from the Recycler Ring project. The total cost of the materials was $1200. If the magnets and steel were purchased the cost would have been an additional $1100 - $2000. Non-exempt labor was 2.5 man-weeks of machining and welding and 3 man-weeks of mechanical technicians.

3 RESULTS

After the magnet was assembled, detailed field maps (of the vertical, or y, component) of the magnet were made. (For reference, we use a coordinate system where the field is along the y direction, x is from the yoke to the open side of the C, and z is parallel to the yoke in the direction of the beam in KTeV). Field measurements are accurate to about 1% and the position measurements are accurate to +/- 2 mm. This is more than adequate for the purpose for which this magnet was built. The results were compared with the expectations based on the PANDIRA calculations. The vertical component of the field as a function of depth in the magnet at y = 0 are shown in Figure 3. The central field was measured to be 416 gauss (compare with 351 gauss expected). The calculated values of the field have been normalized (calculations multiplied by 1.18) to the measured field at the center of the magnet. The calculated and measured shapes of the field are in good agreement.

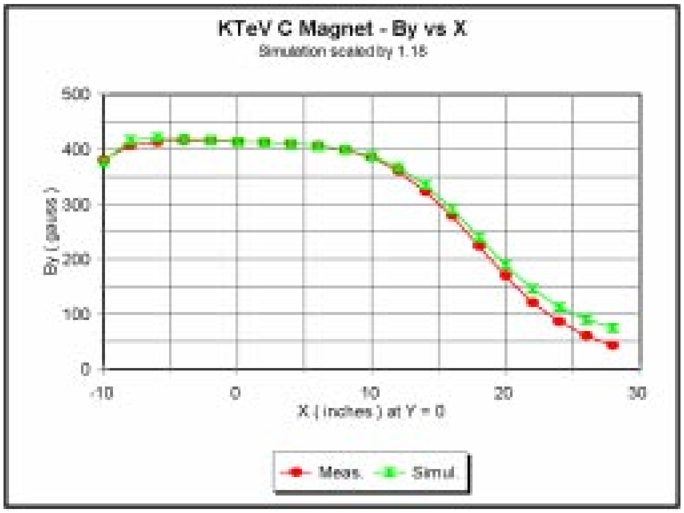

Fig. 3. *A comparison of data to PANDIRA showing vertical (major) component as a function of transverse distance. The inner edge of the side yoke is at x = -10".*

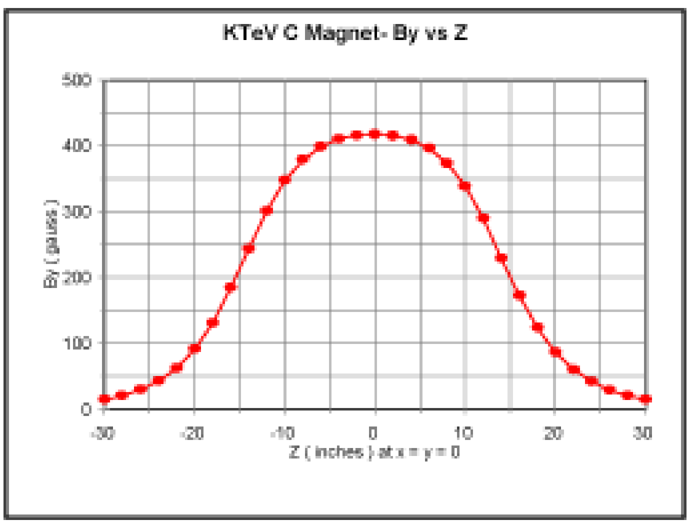

Fig. 4: *Vertical field as a function of longitudinal distance.*

Figure 4 shows the y-component of the field as a function of z. The measured field integral is 333 gauss-meters, or 10.0 MeV/c. Using the maximum field as 416 gauss, this yields an effective length of the magnet of 32 inches. Note that the magnet is not long enough to yield a significant constant field region. This is not surprising, as the length/gap is only about 1.3.

The magnet was found to be very symmetric, the fields above and below the axis being the same to better than 3%. The field integrals are uniform to better than 5% over the 6" x 8" region needed in the experiment.

4 CONCLUSION

A permanent dipole magnet was constructed quickly and inexpensively. Also, the installation time was reduced from days to just one hour. The measured fields matched the expected fields in magnitude as well as expected, and matched the shapes quite accurately. The field could be increased with an additional layer of ferrite bricks, but fabrication would be more difficult.

5 ACKNOWLEDGMENT

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Figures

1. Photograph of C-magnet installed in the KTeV beamline. An electric die-cart was used to adjust the elevation.

2. Front and side view with dimensions.

3. A comparison of data to PANDIRA showing vertical (major) component as a function of transverse distance. The inner edge of the side yoke is at x = -10".

4. Vertical field as a function of longitudinal distance.