PROTOTYPE SECTOR MAGNETS FOR THE GeV ELECTRON MICROTRON (GEM)*

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MASTERIntroduction

Three prototypes of the sector magnets for GeV Electron Microtron accelerators have been designed. One has been built and two are being constructed. The first is a full scale, 168 ton prototype for one-half of a 2 GeV Double Sided Microtron (DSM) sector magnet. The successful fabrication and testing of the pole pieces for this prototype has demonstrated that their required close tolerances for flatness and parallelism can be met. The second magnet is an approximate two-thirds scale model of one step at the low energy end of the hexatron sector magnet designed for the 4 GeV Electron Microtron (GEM).¹ The measured fields demonstrate that the field falls off faster than an "Edge-short-tail"² and error fields are at low levels and are controllable. A third prototype magnet exactly duplicates the full scale geometry of the first three full orbits of the GEM sector magnet from entrance to exit points. It will permit high precision measurements and corrections of field errors and verify the 3-D computer program, TOSCA.³

Prototype Magnet for a 2 GeV Double Sided Microtron

This prototype, illustrated in Fig. 1 below, duplicates one-half of a full scale DSM sector magnet. The pole tip, endguard, coil, and Purcell gap geometries are exact but most of the yoke is made from surplus magnet steel from the former ZGS resulting in a \$750 K saving. Yoke spacers and yoke end blocks were fabricated to complete the major portions of the core.

Fig. 1. Prototype Magnet for 2 GeV Double Sided Microtron.

The magnet was designed to obtain experimental data on the magnetic field and various mechanical characteristics of a large sector magnet. It will enable both low and high energy orbits to be studied and the effects of the pole face correction coils to be investigated. Five correction coils for the high

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energy orbits will be made. It will also permit measurements of structural deflections due to the magnet field and to the thermal gradients in the large structure. Other areas including methods of accurate assembly of large parts will be developed.

The prototype is now being assembled on one of the foundations of the former ZGS ring magnets. A single pole piece was constructed using methods applicable to the actual GEM sector magnet. The pole piece provided data on attainable tolerances, and costs of fabrication, and sonic measurements could be used to locate and size small inclusions near the pole piece surface adjacent to the magnet gap.

Pole Pieces for DSM Prototype

One pole piece (0.19 m x 1.45 m x 6.25 m) for a full scale DSM sector magnet was fabricated as mentioned above; it is shown in Fig. 2. It was machined from a billet of Lukens' "Lectrefine" AISI 1010 steel. This steel was chosen because of its better uniformity. The processing features a unique method of electroslag remelting after the initial rolling to billet size to further reduce non-metallic inclusions such as oxygen and sulfur. This proprietary "Lectrefine" process was developed by Lukens Steel.⁴ The ASTM A578-S9 specifications allow that inclusions equivalent to or smaller than a 1 cm diameter flat bottom hole detectable ultrasonically are acceptable for plates 0.1 m to 0.2 m (4 to 8 in.) thick. (The pole piece is 0.19 m or 7.5 in. thick.)

Fig. 2. Pole Pieces for DSM Prototype.

After the "Lectrefine" process at Lukens but before machining at Bethlehem Corp., the pole piece was ultrasonically tested through its 0.2 m depth for 100% full coverage and no inclusions larger than the 1 cm diameter flat bottom hole were found. After machining and grinding, a higher sensitivity Argonne QAD test was conducted at Argonne to attempt comparisons with a 1.6 mm flat bottom hole in the region approaching the ground surface of the pole piece. Nothing was found until depths beyond 0.02 m

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were reached where one interface of approximately 2.4 mm was located. At a 0.025 m depth only two interfaces approaching 3.2 mm were found. These small interfaces were recorded and mapped to be checked later for any future possible effects in magnetic field found during mapping.

The 6.25 m pole piece was successfully ground at C. O. Hoffacker Co. within the required flatness and parallelism tolerance of 50 μ m (0.002 in.). In fact, all checks for parallelism were within 25 μ m (0.001 in.) and for flatness were within 20 μ m (0.0008 in.) or better. The flatness checks consisted of three scans lengthwise at equal intervals and four scans across the width also at equal intervals. The flatness was measured with a differential electronic pendulum level, Model 232 P-68 made by Federal Products Corp. Figure 2 illustrates the pole piece after it was cut in half to serve as the pole pieces for the model magnet shown in Fig. 1.

Fig. 3. One Step Two-Thirds Scale Model Magnet.

One Step, Two-Thirds Scale Model

The purpose of the one step endguard prototype model magnet shown in Figs. 3, 4, and 6 was to demonstrate that the magnetic edge in the GEM sector magnet design was at least as sharp as the "Engle short-tail edge"² without using excessively thick steel in the endguard or shield plates. This was clearly done as is shown in Fig. 5. The measured field for the endguard model replicates that for the GEM magnet calculations between $x=0.5$ and 3. A comparison between calculation and measurement in this region is, therefore, highly reliable. Some accuracy in the high field region of this model is lost because of the proximity of the corner of the pole tip, and some edge effects could propagate into the measurement region. We may also expect some discrepancies in the high field region due to inaccuracies in the B-H table for the specific unannealed steel used. We believe that the overall agreement between the TOSCA calculation for the full GEM magnet and our existing endguard prototype magnet measurements in the endguard region is excellent. Results from measurements of a variety of shine and endguard geometries show the following:

1. The integral of the quadrupole gradient along the beam path was measured as a function of central field and a variety of endguard geometries, and

was found to be small ($\sim 0.04 - 0.06$ T-m/m at 1 T) compared to the external quadrupoles in the adjacent beam line (~ 1 T-m/m one meter downstream). Thus, the measured quadrupole terms are well within the normal tuning range of nearby quadrupole magnets.

2. Attempts at shimming the magnet have shown that we are able to modify the field easily between the pole tips. We have experimental data at 1 T which lie above the TOSCA curves (and above $B/B_0 = 1.0$) in the region $-2.5 < x < -1.5$ (Fig. 1) and have been able to reverse the quadrupole gradients in this region.
3. Additional improvements are possible by rotating the effective edge of the magnet slightly ($1-3^\circ$), and by additional shimming. These should reduce the measured quadrupole gradient significantly (from the present low values) and reduce the sextupole and higher multipoles below detectable levels. Additional corrections are also possible in the dispersive straight sections.

These results show that field errors are already at tolerable levels and can be considerably improved by a variety of methods.

Fig. 4. Expanded View of One Step, Two-Thirds Scale Model.

Three Orbit Prototype

The third prototype magnet, now being fabricated, exactly duplicates the magnetic field for the three lowest energy orbits in a full sized sector magnet in the hexatron accelerator. It is shown in Fig. 7. The pole tips are being made from fully annealed AISI 1010 steel but the yokes will be AISI 1018 steel. The main and auxiliary coils are being made from the same conductor and are arranged in exactly the same geometry that will be used in a full sector magnet. The magnet will also contain Purcell gaps, endguards, shield plates, and pole tip shims.

Fig. 5. Plots of Endguard Region Magnetic Edge Calculations and the Experimental Results of the One Step, Two-Thirds Scale Model.

Fig. 6. One Step, Two-Thirds Scale Model with Upper Endguard Plate Removed.

The technical aspects that will be studied with this magnet are: 1) the field shape along the beam path; 2) the field shape perpendicular to the beam at the magnet edge, including sextupole and octupole errors; 3) the current regulator for the power supply; and 4) passive and active corrections to the $\int B dl$ for three adjacent orbits. The first two items cover the primary areas for which this magnet is being built. For these the endguard, shield plate, and pole tip shim geometries will be changed as required to obtain acceptable field profiles. The step edge on the third orbit and the common entrance edge will have removable steel parts which can be modified without disassembling the magnet. The pole tip shims held in nonmagnetic carriers can easily be modified. The main coil position will be adjustable relative to the pole edge. This will permit the reduction of the amount that the pole step overhangs the coil (See Fig. 7). Extra steel will be placed between the coil and the pole edge.

The pole face correction coils will also be supported from the pole shim carriers. These coils allow the interactions among the three sets of coils to be studied and to develop the coil control logic.

Fig. 7. Expanded View of Three Orbit Prototype.

An existing high precision measuring system⁶ will be used to measure the magnetic fields of this magnet. It is capable of positioning a Hall probe to within $\pm 25 \mu\text{m}$ parallel to the beam direction and to $\pm 0.1 \text{ mm}$ normal to the beam direction. It measures the magnetic field to 1×10^{-4} or 1 G. These precisions are sufficient to establish the properties of a satisfactory sector magnet field. The measuring system will have to be moved once to get data for all three orbits. This type of operation will be necessary for a full sized sector magnet. The control programs were designed to facilitate this; therefore, this prototype magnet will allow the measuring system to be fully developed to meet its design objectives.

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