PERMANENT MAGNET ASSEMBLY TOOLING FOR THE 8 GEV TRANSFER LINE AND RECYCLER RING AT FERMILAB

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Abstract

Magnets for the beam transfer line between the Fermilab Booster and Main Injector and the Recycler antiproton storage ring are constructed using permanent magnet ferrite bricks surrounding a steel pole and housed inside a steel flux return shell. The transfer line consists of 51 dipoles, 67 gradient magnets, and 8 quadrupoles. The Recycler ring consists of approximately 350 gradient magnets and 60 quadrupoles. Positioning and handling large steel plates lined with magnetized ferrite bricks pose several challenges to the design of assembly tooling. Large attractive forces between mating magnet sub-assemblies must be controlled in order to minimize personnel hazards. Positioning of subassemblies must be precise to allow insertion of mechanical fasteners and to maintain consistent magnetic performance in all similar magnets and provisions must be made for magnet disassembly in the event that repairs or adjustments are indicated by magnetic measurements. This paper describes and illustrates the assembly tooling designed and fabricated to facilitate construction of all of the nearly 500 dipole and gradient magnet assemblies in the 8 GeV beam transfer line and Recycler ring.

1 INTRODUCTION

Unlike their conventional and superconducting counterparts, there is very little about permanent magnet accelerator magnets that is mechanically sophisticated. Their beauty lies in their simplicity and their uniqueness lies in the way they are assembled. Since they can’t be magnetized after assembly, all of the components are either magnetic prior to assembly or strongly attracted to other magnet components during assembly. Anyone who has tried to maneuver two strongly magnetic elements in close proximity to one another can appreciate the unique handling problems one encounters in large permanent magnet assemblies.

Attractive forces vary widely due to differing geometries. For the strontium ferrite bricks used in the 8 GeV transfer line and Recycler, we use 200 kg/meter of magnet length for a row of single ferrite bricks and 400 kg/meter for a double row as the attractive force between two magnetic components in a magnet assembly. These forces are based on calculations and tests conducted during the R&D phase of the 8 GeV transfer line.[1] For magnets like those being built for the Recycler, this translates to an attractive force of nearly 1800 kg between, say the top plate and pole assembly. Forces of this magnitude are both difficult to control during assembly and constitute a serious pinch hazard to personnel. For both of these reasons, to control the forces and to minimize the personnel hazard, we opted early in the R&D phase of the permanent magnet development to fabricate tooling that could be used throughout the R&D and production phases of both the 8 GeV transfer line and Recycler.

2 MAGNET DESIGN

Seven different gradient and dipole magnet designs exist for the 8 GeV beam transfer line and Recycler storage ring, each with different cross sections, lengths, strengths, and magnetic characteristics, but all containing similar mechanical features. It is beyond the scope of this paper to describe each of the designs in detail, however, a brief overview serves as background for a description of the tooling design.

Figures 1 and 2 illustrate a cross section and an exploded isometric projection of one of the gradient magnets being developed for the Fermilab Recycler. It is representative of all the permanent magnet assemblies built for the 8 GeV transfer line and Recycler and consists of a low carbon steel pole assembly surrounded by magnetized ferrite bricks, all housed in a steel flux return shell. Spacers between the individual poles and between the pole assembly and flux return are aluminum. The ferrite bricks are 101.6 mm wide, 152.4 mm long, and 25.4 mm thick. All of the magnets are of similar size, 24 to 30 cm wide and 19 to 25 cm high. Magnet lengths vary from 2.4 to 4.7 m.

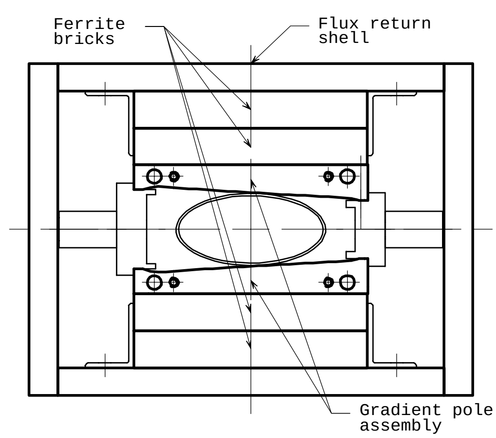

Figure 1: Recycler gradient cross section

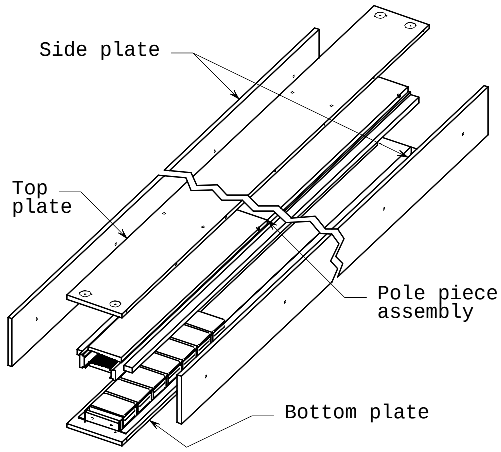

Figure 2: Recycler gradient exploded view

3 TOOLING DESIGN

The design goals for the assembly tooling were apparent during early efforts building R&D magnet assemblies. Controlling the attractive and repulsive forces, aligning mating magnet components, and ensuring personnel safety at all times were the key elements we sought to achieve. Speed of operation was not a strong consideration due to the relative few magnets being built and the fact that final assembly represents only a small fraction of the total time producing any one complete assembly. For these reasons, a high degree of automation was not necessary. A simple set of hand operated controls with appropriate fixturing were more than adequate in the initial design studies and proved to be so in production.

Figure 3 illustrates the result of this design effort. The tooling consists of four key pieces, all of which work together in building each magnet assembly. The main component is the table itself shown in profile on the left side of figure 3. With the exception of guide pins, actuators, bearings, and fasteners, the table is constructed entirely from 6061-T6 aluminum plate and structural members. The table serves as the main work surface and contains guides and motion control devices for the remaining parts. Shown above the table is a lifting fixture used first to lower the pole assembly onto the bottom plate then to lower the top plate onto the pole assembly. The lifting fixture contains features to accurately position the pole assembly and top plate and serves as a stiffener to prevent bending of the subassemblies being lowered as the attractive forces between mating parts increase. It also contains Teflon bushings which align with and slide over precision guides attached to the assembly table. Linear actuators at either end of the table connect to the lifting fixture once it is in position over the table and allow it to be lowered toward the table surface.

Two aluminum channels on either side of the main table are removable and are used as the base for assembly of both side plates. Once complete, the side plates with the attached aluminum channels are lowered onto two stainless steel pins on either side of the table. These pins are connected to handwheel actuated drive mechanisms which allow both side plates to be moved toward the center together.

The upper lifting fixture and side channels have been designed to accommodate all of the various magnet assemblies. Wherever possible, standard spacing has been used for fastener locations in the magnet top, bottom, and side plates to minimize the rework in the assembly tooling between production of the various magnet types.

4 ASSEMBLY PROCEDURE

4.1 Magnet Assembly

Regardless of the magnet type; gradient, dipole, vertical

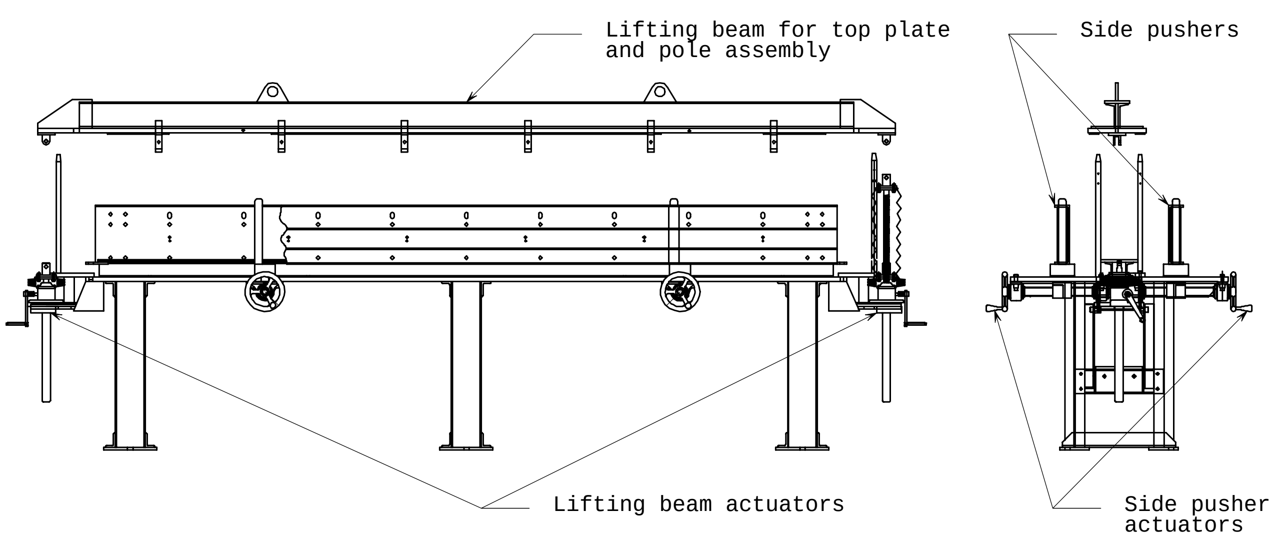

Figure 3: Permanent magnet assembly tooling

bend or dispersion suppressor, the assembly procedures are nearly identical. Each of the four main subassemblies; top, bottom, and two side plates, are completed on separate nonmagnetic work stations. After completion of these subassemblies, each is brought to the magnet assembly table in turn. First the bottom plate with attached hardware and ferrite bricks is attached to the base of the table. Next the pole piece assembly is lifted using the lifting fixture and lowered onto guide rods attached to the table. The lifting fixture positions the pole precisely over the bottom plate and prevents the attractive forces between the pole and bottom plate from bending the pole assembly. Once the pole is in place, the top plate is similarly lowered onto the subassembly of the bottom plate and pole. Finally, each of the two sides, complete with their respective aluminum channel stiffeners are lowered onto vertical guide rods on the assembly table. Once in position, the guide rods are moved uniformly toward the center. An attempt is made to ensure that each side plate contacts the center assembly at the same time.

Once all four plates are in position, mechanical fasteners are installed through clearance holes in the side aluminum channels. When complete, the channels are removed, the magnet assembly is unbolted from the assembly table, the end plates are attached, and the competed assembly is moved to the test area.

4.2 Magnet Disassembly

Although not anticipated in the early design stages, it became apparent early in production that the assembly tooling would be just as valuable for magnet disassembly as it was for assembly. During the R&D phase of each particular magnet design, several attempts are typically necessary to find the exact ratio of ferrite to temperature compensator. There was no way to determine this in advance due to the lack of homogeneity in the bricks and batch variations in the compensator. Complete magnets are built and tested in order to evaluate the degree to which the design field and temperature coefficients are met. If measurements indicate that an adjustment is needed, disassembly is required. Typically, we have had to disassemble at least one magnet at each lot change in temperature compensator. Attractive forces are at a maximum when the gaps between parts are closed as in a completed assembly which makes disassembly without this tooling not only time consuming, but hazardous. Magnets requiring rebuild are fastened to the table and disassembly proceeds in exactly the reverse order from the assembly described earlier.

5 SUMMARY

The assembly tooling developed for the 8 GeV beam transfer line and Recycler ring has proven itself to be both versatile and flexible. More importantly, however, it has allowed us to control the inherent forces which exist in these assemblies, routinely assemble magnets with the required precision, and to do both with minimal hazards to personnel.

REFERENCES

[1] "Ferromagnetism", Richard M. Bozorth, IEEE Press, New York, 1978.