AUTOMATED PERMANENT MAGNET MAGNETIZATION SYSTEM FOR 8 GEV TRANSFER LINE AND RECYCLER RING PRODUCTION AT FERMILAB*

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Abstract

The Recycler antiproton storage ring and the 8 GeV beam transfer line between the Fermilab Booster and the Main Injector 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. These magnet assemblies are being produced at Fermilab currently and as a part of the tooling required to produce these assemblies we have designed, built and put into production an automated permanent magnet magnetization system. The system includes a conventional B-2 type dipole, a Programmable Logic Controller (PLC) controlled brick mover, a hall-probe measurement station and an IBM Compatible P.C. for data acquisition. The system has been used in the production of the 8 GeV beam transfer line magnet assemblies each requiring several hundred individual permanent magnets. This paper describes and illustrates the design of the automated system, the data acquisition, use of FEA analysis in the design, and the experience we have had using this production system.

1 INTRODUCTION

The Fermilab Permanent Magnet Magnetizer System was developed to produce saturated permanent magnet bricks to be used in the construction of permanent magnet assemblies for the 8 GeV Line and the Recycler Ring for the Main Injector Project. The new system replaces an existing manual system for the saturation and measurement of YBM-2b Permanent Magnet Bricks. There are several sizes of bricks used in the construction of the magnet assemblies, namely 4" x 6" x 1", 3" x 4" x 1" and 2" x 6" x 1". The magnetizer system is designed to shuttle an unsaturated permanent magnet brick into the aperture of a conventional dipole, energize the dipole, saturate the brick, shuttle the brick to a measurement fixture, and record the field measurement. The system also provides operator feedback to sort acceptable bricks from those which lie outside the required field strength range. The Fermilab Permanent Magnet Magnetizer System was put into operation on July, 30th 1996 and has been useful in magnetizing all the bricks used in the 8 GeV Transfer Line which operated successfully at Fermilab on February 20th, 1997.

FIGURE 1. MAGNETIZATION SYSTEM AT FERMILAB

* Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy

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2 THE CONTROL SYSTEM

The automatic control of the mechanism is accomplished using a GE-Fanuc Series 90-30 programmable logic controller (PLC). The system also has a Personal computer for data logging. We have used an IBM 386 clone in this case. The PLC has an ASCII BASIC module which runs a small basic language program to supply the Hall probe readings to the PLC registers. The PC runs a program written in MS-Quick Basic which communicates with the registers of the PLC to read and record the current hall probe measurements. The PC has several programs written in MS-BASIC which run the machine in automatic mode for saturation, automatic mode for measurement only and a small program to toggle the PLC run states. The small program to toggle the PLC from Stop/Outputs Disabled mode to Run/Outputs Enabled is used if the PLC shut down on an interlock violation. A conceptual drawing of the control system follows as figure 2.

3 THE MECHANISM

The brick shuttle mechanism includes a half horsepower DC motor which drives a timing belt to which is attached an aluminum carriage running on aluminum rails. The carriage contains the permanent magnet brick and has a sliding cover which captures the brick in its entirety. The cycle starts with the brick holder carriage at its home position where a brick is loaded into the carriage and the cover closed. After the cover is closed, the operator hits the cycle start buttons and the carriage begins to travel into the dipole aperture. The carriage moves at a high rate of speed until it hits a downslope switch which sets a lower speed and slows the carriage down to a soft stop at the end of travel micro switch. The conventional dipole is energized automatically and the brick is saturated. After a short time, the carriage is driven to the measurement fixture where a Hall probe measures the field strength and this data is sent to the PLC. The data is then logged to a PC from the PLC, the carriage returns to the home position using the same high speed-low speed method used at the dipole position where the operator then unloads the saturated brick and inserts an unsaturated brick. And the cycle begins again. The current cycle time excluding brick handling time is 13 seconds per brick.

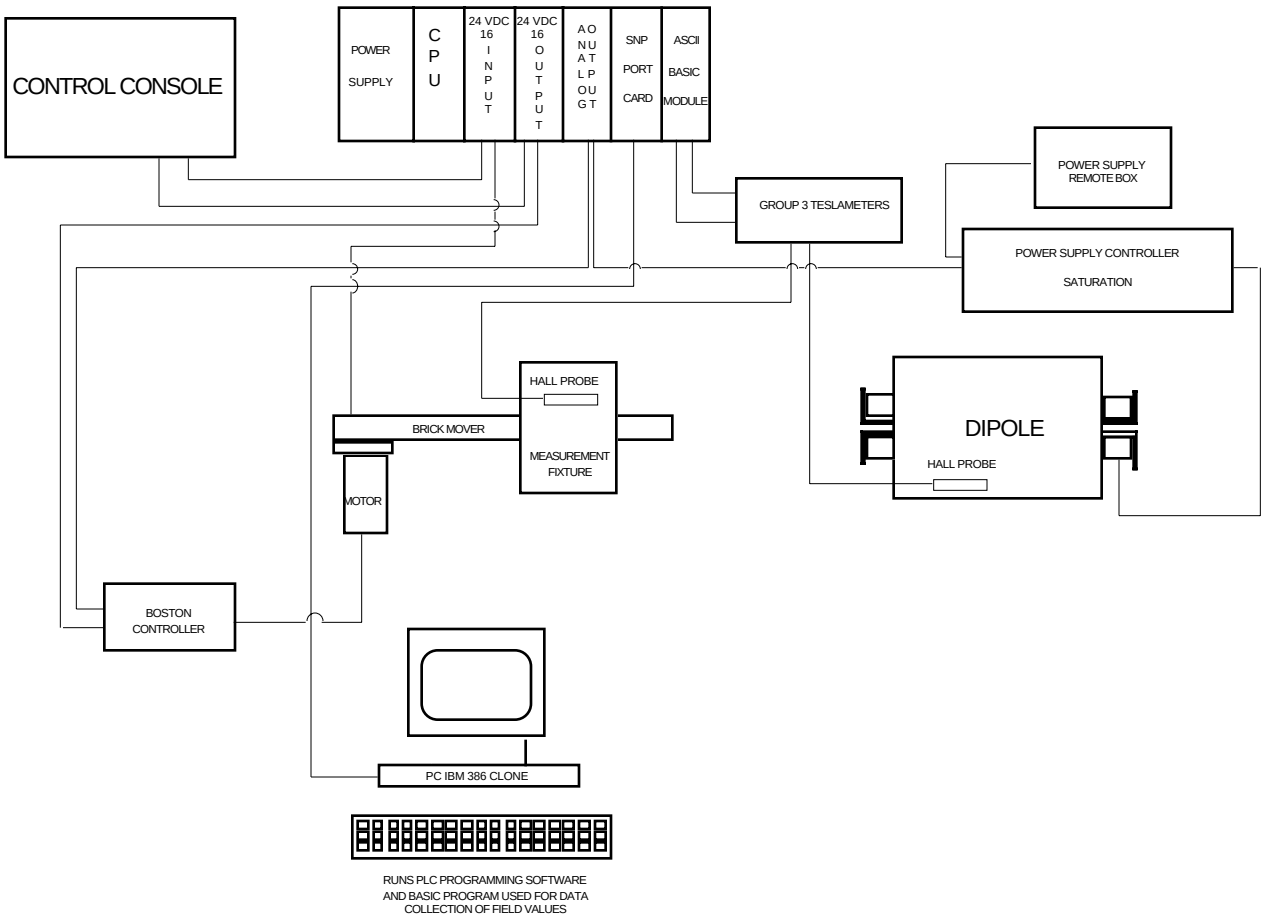

FIGURE 2. MAGNETIZATION CONTROL SYSTEM CONCEPTUAL LAYOUT

4 MAGNETIC MEASUREMENTS

Finite Element Analysis (Ansys) was employed to aid in the design of the measurement fixture. The flux return for the measurement fixture was made out of conventional Main Injector ring dipole lamination steel. The steel was plentiful at Fermilab and its magnetic properties were well understood. The original pole piece for the fixture was a laminated design which was discovered to have a positional sensitivity of 20 gauss per inch of carriage travel due to the fact that air between lamination layers has the effect of bunching the flux in the center of the fixture and no hard stops are employed to stop the brick holder carriage precisely at the measurement fixture. The measurement fixture pole piece was replaced with a solid steel pole which distributed the flux more uniformly but also had the effect of lowering the magnitude of the average magnetic flux density measurement from 920 gauss to 813 gauss. The position sensitivity went from 20 gauss per inch to 2.5 gauss per inch or less than 1% error due to positional inaccuracies. Finite element analysis was also used to verify that the magnitude of the magnetic flux density measurement was reasonable. The magnetic inductance was found by analysis to be 813 gauss and the average measured at the Fermilab production facility was 786 gauss which is within 3.5%.

5 FUTURE DIRECTION

This system works well and was used in the production of the saturated permanent magnet bricks for use in the 8 GeV line permanent magnet assemblies. These magnet assemblies were produced at the rate of 2 magnets per day and required about 200 bricks per magnet. Fermilab is currently designing a higher capacity production system which is based upon this design without measurement capability for the Recycler Ring bricks. The carriage in this particular version will be designed to carry 4 bricks into the dipole aperture. The new system is scheduled to be completed in July of 1997.