MAGNETIC FIELD MEASUREMENTS OF THE INITIAL FERMILAB MAIN INJECTOR PRODUCTION QUADRUPOLES


Abstract

A large sample of the 2.54-meter quadrupoles for lattice matching in the Fermilab Main Injector have been fabricated and measured. The resulting properties are reported and compared to the accelerator requirements.

I. Magnet requirements

The Fermilab Main Injector is a new proton and antiproton accelerator currently under construction at Fermi National Accelerator Laboratory. It will replace the existing Main Ring in all functions. While many of the quadrupoles used in the Main Injector will be reused from the Main Ring, the lattice requires some new quadrupoles of the same design but different lengths (2.54 m and 2.96 m, compared to 2.13 m for the Main Ring quads) to run on the same busses. The performance requirements of the quadrupoles have been studied extensively [1] [2] [3]. The two significant areas of magnetic performance are the strength we quote fraction differences in “units” of parts in $10^4$. Properly centered, the dipole component $b_1$ is zero.

From the symmetry of the magnet design we expect the field to have significant quadrupole, octupole, and twelve-pole components. For our tracking studies we have assumed distributions of the forbidden components that are consistent with the measured spread in values. While these values are larger than the measurement errors and not yet understood, they have no significant impact on the beam dynamics. We concentrate here on the allowed components.

Given the known octupole component in the existing Main Ring quadrupoles, we could choose the octupole of the new quads to meet the beam dynamics needs. The octupole has two demands placed upon it. One need is that the dynamic aperture be large enough to meet the accelerator requirements. The beam should not fall out of the machine on its own. The other need is that the beam be close enough to the edge of stability so that the existing trim octupoles can bring the beam to the point of slow extraction. The beam should fall out of the machine given a little push in the right direction. Based on simulations, an average of 4 to 8 units appears to satisfy both requirements. Magnet-to-magnet variations are not significant dynamically.

The twelve-pole component is clearly measurable, but not large enough to pose a problem for the dynamic aperture of the accelerator. Reasonable variations in the twelve-pole are not significant.

II. Measurement systems

The equipment and software used in measuring the magnets is described with more detail in other papers at this conference and elsewhere [4]. The request from the Main Injector project is that every magnet be measured and that in production the strength and shape be determined by at least two independent methods.

To date only a rotating coil system, using a Morgan coil that extends through the length of the magnet, has been implemented. The probe has two orthogonal dipole coils, two orthogonal quadrupole coils, and one each sextupole, octupole, decapole, 12-pole, and 20-pole coils. One quadrupole coil is used to measure the strength of the magnet. The other coils measure the harmonic components while suppressing the signal from the quadrupole field. The rotating coil measurements are performed at multiple currents on every magnet.

A single wire stretched wire system is currently being commissioned. This will provide the redundant strength and shape information requested, as well as magnet center data.

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III. Measurement Data

A. Strength

We have averaged the strength at each current. Figure 1 shows the deviation of the average strength from a linear excitation calculated assuming infinite steel permeability.

![IQC mean strength vs current](image1.png)

To present the magnet-to-magnet variation, we calculate the fractional deviation of individual magnets from the average. Figure 2 shows the strength at 500 A for all magnets in the sample, relative to the average of all magnets except the first seven. Those seven magnets are significantly different from the later magnets due to experimental modifications of the lamination. In the low current regime the strength is dominated by the geometry, with only a small contribution from the permeability of the steel. Note that the strengths are tightly clustered, indicating good control of the geometry. All magnets fall within the expected range. Similarly, even as the steel begins to saturate, the spread in strength is small, as shown in Figure 3.

![IQC strength at 500 A](image2.png)

B. Shape

Figure 4 shows the average octupole $b_4$ as a function of current. This meets both the need for stability and for slow extraction. The octupole strengths are histogrammed in Figure 5. All magnets fall near the target values, and the average is certainly acceptable. The distribution of the twelve-pole component at 1500 A is shown in Figure 6. It is also within the established limits.

![Normal octupole vs current](image3.png)

IV. Conclusions

The Fermilab Main Injector project is well into production of the new quadrupoles for the ring. By the end of March 1995 30 2.54 m quadrupoles, out of 32 required for the ring, had been completed and measured. Magnet performance is within the acceptable range established through tracking studies. Production had just begun on the 48 2.96 m quadrupoles that are required.

References

Figure 5. Distribution of octupole strengths at 1500 A

Figure 6. Distribution of 12-pole strengths at 1500 A


