EXCITATION CHARACTERISTICS OF FERMILAB MAIN INJECTOR DIPOLES AND MAGNET ASSIGNMENT TO REDUCE CLOSED ORBIT ERRORS

P.S. Martin and C.S. Mishra
Fermi National Accelerator Laboratory*
Batavia, Illinois 60510

Abstract

The Fermilab Main Injector project is building 344 dipoles, produced from steel with varying magnetic properties. The strategies for assigning dipoles, based upon their strength characteristics, are discussed. The closed orbit errors due to the strength variations are expected to be small in comparison to alignment errors.

1 INTRODUCTION

The Main Injector accelerator [1] will be constructed using 344 new conventional dipole magnets [2-3]. The new magnets consist of 216 6-m dipoles and 128 4-m dipoles. The 6-m dipoles are divided into two types with different styles of electrical and cooling connections, referred to as IDA and IDB dipoles; similar, there are two types, IDC and IDD, of 4-m dipoles. A given location in the lattice can use only one type, i.e. an IDB cannot be used in a location for which an IDA magnet is intended. The goal for dipole strength variations was to have a distribution of all strengths with an rms width of less than 0.10%. If that could be achieved, then the dipoles could be placed randomly in the ring and the closed orbit errors arising from the strength variations would (i) be correctable with the independent trim dipole correctors being fabricated, and (ii) would be comparable to the closed orbit errors arising from misalignments of the quadrupole magnets.

2 DIPOLE STRENGTHS

The dipoles for the Main Injector fall into three categories. First, twelve preproduction dipoles, three of each of the four different magnet types, were built using steel from one vendor (Armco). These were uniform in relative strength, but were about 1% too strong relative to later production. They were subsequently machined [4] to reduce their high-field strength to more closely match the production magnets. The production of the remaining dipoles used steel from another vendor (LTV Steel). The steel used in the early production dipoles had different B(H) characteristics than the later production, [5] and consequently, the first fifty magnets (approximately) were weaker by as much as 0.4% than the remainder of the production. The relative strength at 1.38 T of all the dipoles produced and measured to date are shown in Figure 1. In this plot, the Armco steel preproduction magnets are shown with negative abscissa.

As can be seen from this figure, the dipole strength rose during the first fifty production dipoles up to the nominal level, then remained within the band ±0.12%. The rms of the production dipoles after the first fifty is only 0.04%. The rms of the entire distribution, including the modified Armco steel dipoles, is less than 0.12%. However, the sample is certainly not a Gaussian distribution. While it appears likely that we could easily have endured the effects of randomly placing the dipoles in the ring, the production and installation schedule afforded us ample opportunity to minimize the closed orbit effects by assigning dipoles based upon their strength characteristics.

The sole criterion used in assigning magnets is that in Figure 1, the strength at 1.38 T. This field corresponds roughly to 120 GeV, the energy at which most Main Injector extractions take place, in particular the fixed target program with resonant extraction from the Main Injector. With injection at 8 GeV, the dipole correctors can easily handle rather large strength variations at that energy. Tevatron injection takes place at 150 GeV; it is hoped that by having a good orbit established at 120 GeV, the corrections needed to control the orbit at 150 GeV will be minimal. Other aspects of the dipoles, e.g. field shape, can be found elsewhere [6].

The phase advance per cell in the Main Injector lattice is close to 90°. This permits us to place magnets of the same type, e.g. two IDAs, one cell apart to produce a local orbit distortion with essentially no effect on the closed orbit in the rest of the ring. Orbit calculations are done using a detailed Main Injector lattice and the program TEAPOT. Special handling is obviously required for the preproduction dipoles and the weaker early production dipoles, placing them one cell apart. For the production dipoles, with their tighter distribution of strengths, the only measure taken is to ensure that no two adjacent dipoles have a greater than two standard deviation (of the same sign) strength variation from the mean. This technique has been applied in a series of episodes during the past fifteen months. By the time the FMI ring

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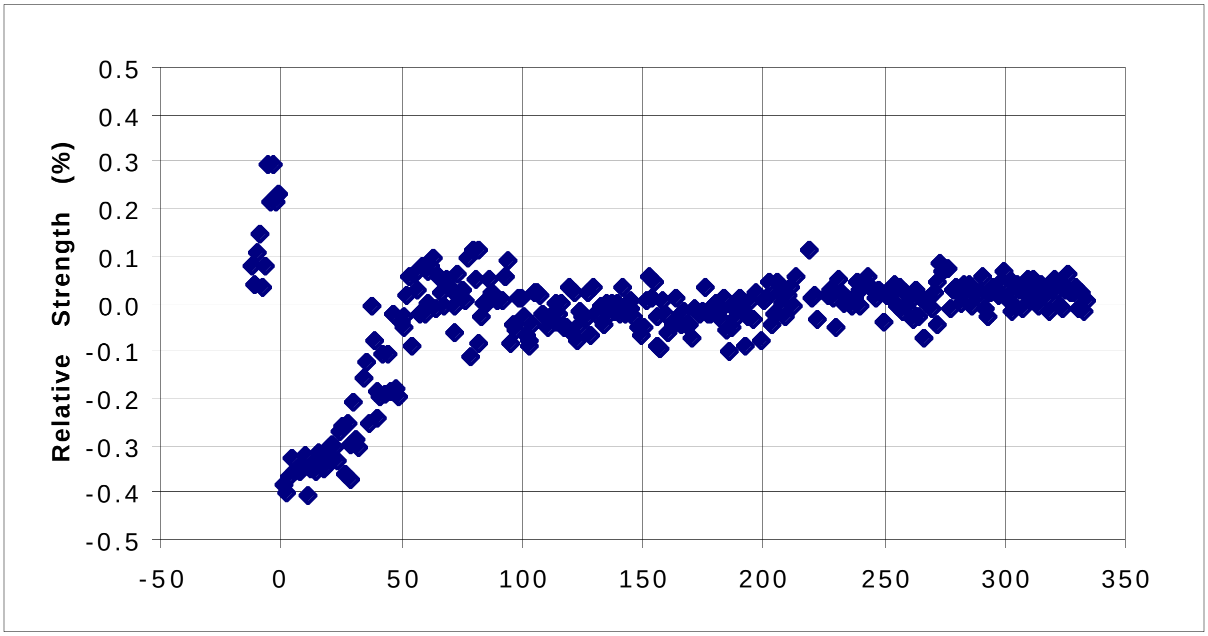

Figure 1. Relative strength of all dipoles produced to date, in approximate order of production. The pre-production dipoles are at the left.

enclosure became available in December, 1995, for the installation of utilities followed by magnet stands and magnets, a large inventory of magnets(~150) had been fabricated and measured. These were assigned and installed during the period February through April, 1996. As additional magnets are fabricated, we wait until thirty to forty magnets are available (about three months of production) and then assign and install them in a period of about one week. At this point in time, 297 dipoles have been assigned to the ring, of which 280 have been installed. Because of the strength variations observed, dipoles have also been assigned as spares, so that single-magnet replacements can be made without serious impact on the closed orbit.

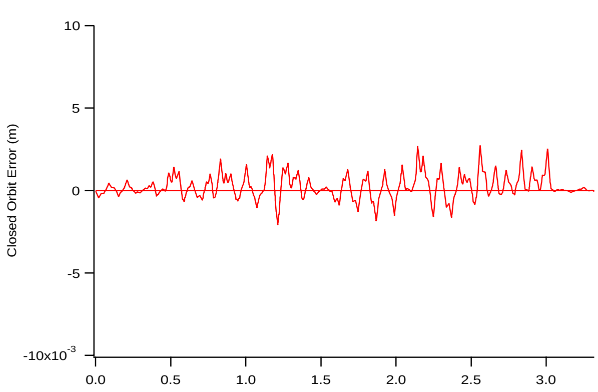

Figure 2. Closed orbit error due to dipole strength variations.

The expected closed orbit distortion resulting from the variations in dipole strength of all the magnets assigned to date is shown in Figure 2. The distortion is less than 3 mm everywhere. The correction dipole magnets being fabricated [7] for the Main Injector have the capability of correcting errors up to 7 mm at 120 GeV, and therefore can easily correct these errors. At commissioning time, closed orbit distortions from alignment errors are expected to be larger than those due to the dipole strength variations.

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