Study of the Main Injector Quadrupole Measurement Precision

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

April 14, 1994

In this paper we discuss calculations done to study the measurement precision required in the measurement of the quadrupole strength. Our analysis shows that a measurement precision of 5 units or better should be maintained.

I. INTRODUCTION

The Fermilab Main Injector (FMI) will use 128 recycled 84" long quadrupoles from the Main Ring. The FMI will also have newly constructed 100" and 116" quadrupoles of similar design. We plan to measure the strength and multipoles of all of these quadrupoles magnets before they are installed in the ring. The dynamical aperture of the FMI depends on the variation in the quadrupole strength and the octupole component present in the magnetic elements. Using the previous measurements of the Main Ring quadrupoles we know that these quadrupoles have a large octupole component (about 5 Units) and the variation is the quadrupole strength has a sigma of 24 units[1,2]. In this note we have studied the required measurement precision for the quadrupole strength using TEAPOT[3] and a monte carlo program. This precision is required to maximize the dynamical aperture and minimize the variation in Beta function throughout the ring.

II. MONTE CARLO PROGRAM

A Monte carlo program was written to generate a gaussian quadrupole random error distribution of a know sigma and certain number of quadrupoles. Fig. 1 shows the random error distribution using this program for a sigma of 24 units. In Main Ring we have 196 quadrupoles and we need 128 of them for the FMI. We use this Monte carlo program to generate the error distribution for 196 quadrupoles, currently present in the Main Ring, with a 24 units sigma. Using this distribution Fig 2. the quadrupoles were divided into two sets. All

*Operated by Universities Research Association under contract with the Department of Energy

quadrupoles with larger than mean strength were selected as focusing quadrupoles, whereas one with smaller strength were placed as defocusing quadrupoles. Similar distributions were also generated for 116" quadrupoles. These calculation were done with a MI18 lattice file which does not explicitly contains 100" quadrupoles. Hence the number of 84" and 116" quadrupoled scaled properly.

As we had speculated earlier quadrupoles with an error of less than 24 units (one sigma) were needed and used in the FMI simulation. The effective sigma of this simulated quadrupole distribution is about 7 units. TEAPOT read in these files of quadrupole random error distribution for the tracking calculations.

. III. TRACKING CALCULATIONS

The study of the required measurement precision of the quadrupole strength was made by studying the change in the beta function. We are required to minimize the variation in the beta function at injection to control the closed orbit at three local bumps in the lattice and also for a smooth slow extraction of 120 GeV beam. Fig. 3 shows the percentage change in beta function due to an addition of simulated quadrupole random error. The maximum variation of about 3.5% in beta function is only due to the quadrupole strength variation. Other magnetic and alignment errors were included in both the calculations. The mean of the beta function variation is 6%[2] when all the errors are present. Similar number of calls to random number generator were made in both cases to eliminate the difference due to random number generator.

In order to study the effect of measurement error, a quadrupole strength measurement error of known sigma 2 or 5 or 10 units was randomly superimposed on the simulated random error distribution. A cut at 3 sigma was made for the measurement error. This will mainly effect the quadrupoles at the two edges of the distributions.

Fig. 4,5, and 6 shows the change in beta function, i.e. difference in beta function between before and after the addition of measurement errors of 2, 5, and 10 units respectively. It is clear from these figures that a measurement error adds additional beta function error. A measurement error of 10 units corresponds to an additional 2% of beta function variation. This is about half of the actual variation due to quadrupole strength variation. It should be noted that for some seed this additional variation will have same phase and hence it will add to the actual variation, where as for some seed this will have opposite phase and will cancel. Here we are concerned with the worst situation and conclude that a measurement error of 10 units is large. A measurement error of 5 and 2 units gives a maximum beta function variation of about 1% and 0.5% respectively. This will give an additional 25% or 12% of the beta variations. We know that a measurement accuracy of 2 units is hard to achieve. We believe that we should be able to correct additional variations due to 5 units of measurement error. We request that quadrupole measurement accuracy of 5 units or better should be achieved.

We have also studied this from a hypothetical point of view where we considered the actual quadrupole strength variations to be 5 units. The actual strength variation of 5 units is not indicated by any data we have on Main Ring quadrupoles. Fig. 7 shows the