



**Fermi National Accelerator Laboratory**

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# Modification of the Horizontal Dispersion in the Fermilab Main Ring with Additional Quadrupoles

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## Abstract

In the normal Main Ring lattice, the horizontal dispersion includes a dispersion "wave" which peaks at 6.2 meters because the horizontal dispersion of the arcs is not matched into the straight sections. Six additional small quadrupoles have been installed, one in each sector, and powered at low energies (up to 30 GeV) in order to reduce the amplitude of the dispersion wave. The maxima of the dispersion function were thereby reduced to less than 4.7 meters, thus improving the momentum acceptance of the Main Ring. Measurements of the modified dispersion function agree well with the expected values.

## Introduction

The original Main Ring lattice has six-fold symmetry. Each superperiod contains a long straight section, while two additional straight sections, called medium and mini-straight, occur within the arc region in each sector. The medium straight sections have half the normal bending angle of the regular FODO half-cells, while the mini-straight sections have 3/4 of the bending angle of the normal FODO half-cells. The dispersion function is not matched between the arcs and the straight sections, producing a wave with a peak value in excess of 6.2 meters. Matching the dispersion [1] induced by these three sources would require multiple quadrupole circuits. A simpler solution was found, namely the introduction of six additional quadrupoles, one per superperiod. Powered until the beam energy reaches 30 GeV, they reduce the amplitude of the dispersion wave throughout the ring without significantly changing the other lattice functions. The peak values of the dispersion function were lowered to 4.7 meters.

With the advent of the Tevatron and especially its collider mode, the role of the Main Ring in Fermilab operations has changed drastically with respect to the period when it only served the 400 GeV program. The new and diverse functions of the Main Ring necessitated significant modifications. Two vertical overpasses around the B0 and D0 Tevatron detectors transformed the Main Ring into a nonplanar ring. A number of new injection and extraction systems introduced new horizontal and vertical aperture restrictions. These include various magnets for the antiproton transfer into the Main Ring as well as for the proton and antiproton extraction to the Tevatron and the proton transfer to the antiproton production area. The

high values of the horizontal dispersion at horizontal aperture restrictions represent a special beam loss hazard. The contribution of momentum spread to the horizontal beam size, which is particularly important from injection energy through the transition energy, is reduced by lowering the horizontal dispersion function.

## Theoretical Predictions

In various machines including the Fermilab Booster, fast-pulsed quadrupoles have been used to implement transition-jump systems. The correction of the dispersion function in this report with additional quadrupoles is comparable to that which occurs in these so-called  $\gamma_t$  jump schemes. This report represents a modification of the dispersion function towards lower dispersion values, contrary to the  $\gamma_t$  jump where dispersion often reaches higher values. As in the  $\gamma_t$  jump, it is important to keep the tunes unchanged. In the scheme described here, the change in the tunes is compensated by the main quadrupole buses. Furthermore, the magnetic field within the additional quadrupoles just tracks the main quadrupole field and does not change fast as in the  $\gamma_t$  jump. The normalized dispersion function [2] in a part of the B sector is presented in Figure 1.

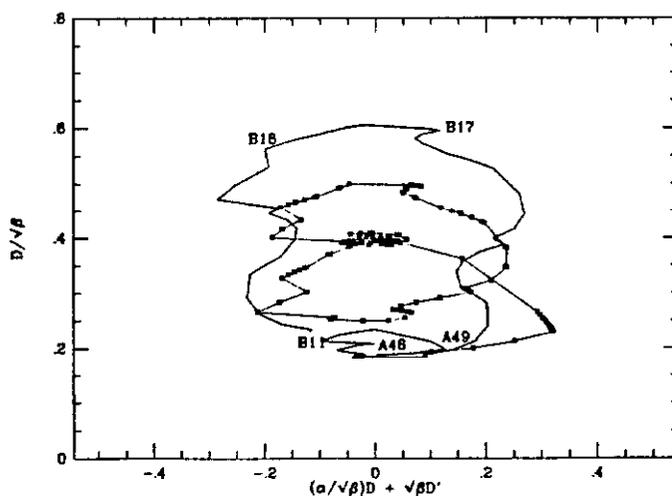


Figure 1. Normalized horizontal dispersion function in the first part of sector B of the Main Ring without (—) and with (· · · · ·) additional quadrupoles.

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The vertical axis  $\xi$  and the horizontal axis  $\chi$  are defined as  $\xi = D/\sqrt{\beta}$  and  $\chi = \dot{D} * \sqrt{\beta} + \alpha * D/\sqrt{\beta}$ , where  $D$  and  $\dot{D}$  are the dispersion and the slope of the dispersion function, respectively. If the straight sections were matched to the arcs, the maximum values [1] of the dispersion would be 4 meters. The normalized dispersion functions of a dispersion-matched lattice would produce a very small trapezoid located at the middle of the circular part presented in Figure 1 (this was already shown in reference [2]). The dispersion vector parallel to the horizontal axis at the top of Figure 1 (from B17 to B18) corresponds to the medium straight section. The long straight section may be distinguished as another dispersion vector at the bottom of Figure 1 (from A49 to B11) in the same vector direction. The short straight section is just upstream of the long straight sections (from A48 to A49). The additional quadrupole was placed 180 degrees upstream of the beginning of the long straight section, thus opposite the long straight in Figure 1. As previously presented [3], the effect of the quadrupole on the dispersion function is similar to the single dipole kick. The change in the slope of the dispersion function  $\dot{D}$  in the thin lens approximation is  $\Delta\dot{D}_i = -q * D_i$ , where  $q$  is the strength of the local quad ( $q = 1/f$ ). The horizontal dispersion function was calculated with the SYNCH computer program. The dispersion in a single sector of the Main Ring with and without the additional quadrupoles is presented in Figure 2. The additional six quadrupoles reduced the maximum of the dispersion function almost to the value of the dispersion-matched ring.

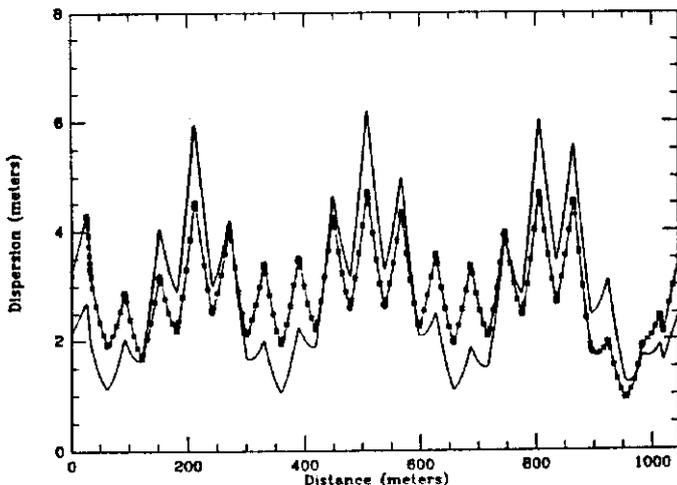


Figure 2. The horizontal dispersion function in a Main Ring sector without (—) and with (---) additional quadrupoles.

## Experimental Results

Six quadrupoles were installed in the Main Ring in 1990. They were connected to the same kind of power supply and controlled with the same program as the other ramped devices. Measurements of the horizontal dispersion function at the injection energy (8 GeV) and at the "flat top" energy (150 GeV) were first performed with the regular lattice. By changing the RF frequency, the horizontal orbit was displaced radi-

ally outside and inside of the central orbit at 8 GeV and 150 GeV. The momentum offset of the beam was calculated from the RF frequency measurements via  $\delta p/p = (\Delta f/f)/\eta$ , where  $\eta = 1/\gamma^2 - 1/\gamma_i^2$ . Dividing the beam position displacements at the the horizontal beam position monitors (BPM) by the beam momentum offset yields 108 values of horizontal dispersion. The horizontal dispersion measurements of the normal Main Ring at beam energies of 8 GeV and 150 GeV agree fairly well with the predicted dispersion values (obtained from the SYNCH calculations). Figure 3 represents the measured and predicted values of the horizontal dispersion function at the positions of the BPM's at 8 GeV.

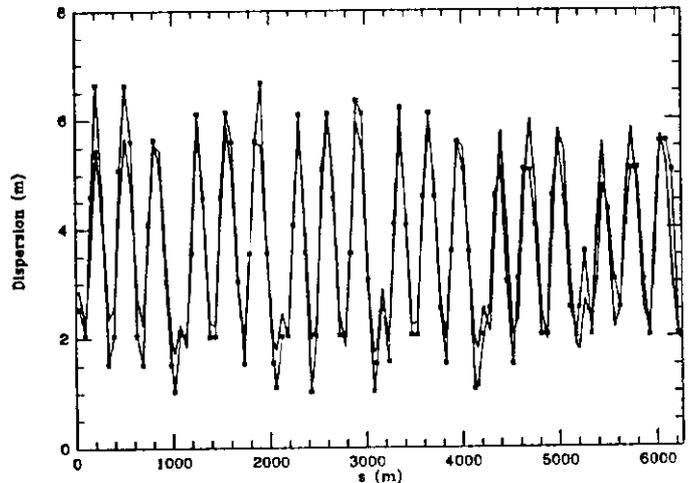


Figure 3. The measured (—) and predicted (---) horizontal dispersion function at 8 GeV in the Main Ring at the BPM's in the normal lattice without the additional quadrupoles.

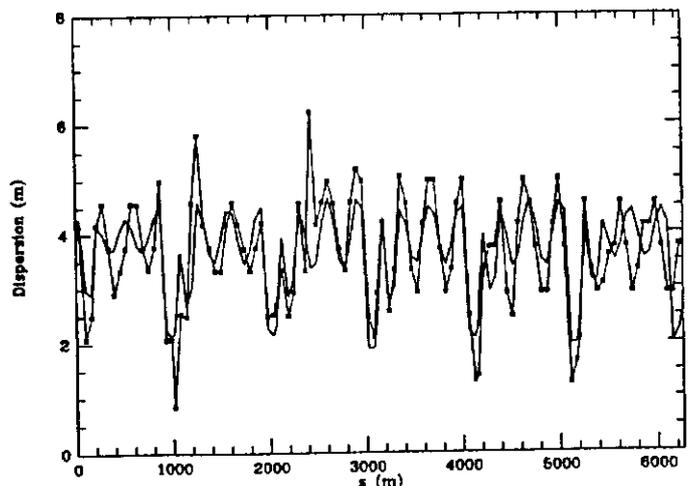


Figure 4. The measured (—) and predicted (---) horizontal dispersion function in the Main Ring at 8 GeV with the additional quadrupoles.

The momentum offset of the beam is also estimated by the program which displays the BPM data. Using the horizontal dispersion functions calculated by SYNCH, the program estimates the momentum offset  $\delta p/p$  by a one-parameter least-squares minimization procedure:

$\delta\chi^2/\delta\Delta = 0$ , where  $\chi^2 = \sum_{i=1}^{106} [x_i - D_i * \Delta]^2$ , and where  $\Delta = \delta p/p$ . For momentum offsets during the radial displacement not exceeding 0.1%, the momentum offset estimates from BPM and frequency data agreed to better than 6%. Studies with additional quadrupoles in operation were performed using a special ramp with a 26.9 GeV flat-top.

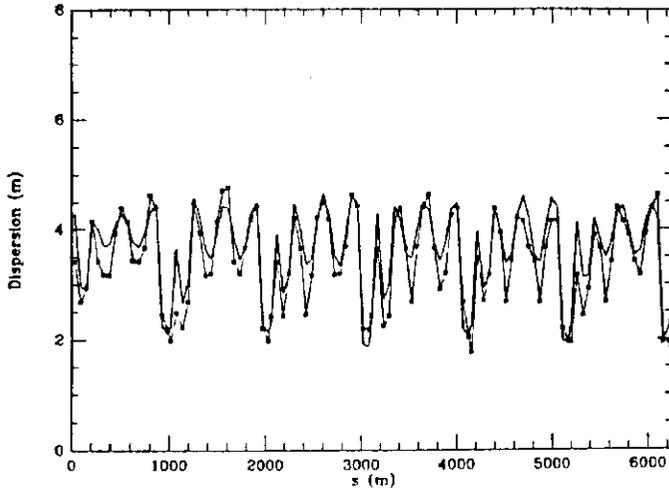


Figure 5. The measured (—) and predicted (-\*-) horizontal dispersion function in the Main Ring at 26.9 GeV with the additional quadrupoles.

Figures 4 and 5 represent the measured and predicted values of the horizontal dispersion function at the BPM's at 8 GeV and 26.9 GeV, respectively, while operating the Main Ring with the six additional quadrupoles.

The tunes were kept at the same values by adjusting the two main quadrupole circuits. The transition energy of the lattice changed from 18.729 GeV to 18.875 GeV when the Main Ring was operating with the additional quadrupoles.

## Conclusion

Six additional quadrupoles in the Main Ring reduced the horizontal dispersion from maximum values of 6.2 meters to 4.7 meters. Measurements of the horizontal dispersion function agree very well with the values predicted by SYNCH at 8 GeV and especially at 26.9 GeV. The strength of the additional quadrupoles allows only a limited range of operation - up to 30 GeV. They provide an important reduction of beam size at injection and at transition (18.73 GeV). These six additional quadrupoles will be used during the regular operation in the next run. A similar configuration incorporating fast quadrupoles might provide a  $\gamma_t$  jump capability; in that case, tune changes would be canceled by the addition of six more quadrupoles.

## References

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