DESIGN AND COMMISSIONING OF THE DO VERTICAL NONDISPERSIVE OVERPASS IN THE FERMILAB MAIN RING

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Abstract:

A new vertical overpass in the Fermilab Main Ring around a future DO proton-antiproton collision detector was designed and built to raise the initial luminosity for collider physics. The new overpass provides a better dispersion match between the Main Ring and the Tevatron, and in the Main Ring substantially lowers the vertical beam size arising from momentum spread. This has also improved the overall efficiency and beam intensity of the Main Ring. Vertical dispersion was measured before and after completion of the new overpass. A high degree of correspondence was obtained between the predicted and measured values of vertical dispersion around the whole Main Ring.

Introduction

The Fermilab Main Ring (MR) became the first nonplanar synchrotron after two vertical overpasses were built around the Tevatron (TEV) BO and DO proton-antiproton collision detectors. The MR magnets in the central part of both BO and DO overpasses were raised with respect to the previous MR horizontal plane up to 5.76 meters and 1.42 meters, respectively. The BO overpass was built in a new tunnel around the collision detector [1] while the DO overpass remained almost entirely within the main accelerator tunnel.

The source of the vertical dispersion ($D_y \equiv p*\delta x/\delta p$) is a vertical dipole magnet where particles with higher/lower momenta are bent less/more with a difference in the bending angle of $\Delta\theta \simeq \theta_o * \delta p/p$ where θ_o is the magnet bending angle. Vertical dispersion in the nonplanar synchrotron due to the vertical dipoles could be canceled outside of the overpass if the dipoles are correctly placed in the lattice. In other words in the correct overpass the superposition of the betatron dispersion waves induced by each dipole should make the resulting wave outside of the overpass equal to zero. The BO overpass was built following the principle of the "Collins" bump [1] with a 360 degrees difference in the betatron phase between the first and third, and between the second and fourth kick. This overpass induces a small (0.4 meters peak) vertical dispersion wave in the rest of the ring. The previous DO overpass produced a larger dispersion wave with a 1.7 meters peak.

There were two major reasons for building a new DO overpass: to raise the luminosity during proton-antiproton collisions in the TEV-Fermilab superconducting synchrotron by eliminating the dispersion mismatch between the MR and the TEV and to lower the vertical beam size arising from beam momentum spread. The vertical dispersion at the extraction location in the MR with the previous DO overpass measured 1.6 meters with a slope of -0.018 meters. To fulfill the dispersion match with the TEV a value of D_y=-0.625 meters (with a zero slope due to the antiproton injection from the oposite side) is necessary. The new DO overpass had to fulfill many geometrical and practical constraints; it had to remain within the existing accelerator tunnel producing a local vertical orbit bump; if possible all vertical dipoles were to be connected to the same electrical bus, all magnets were to be of the same strength.

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Design Method

The thin element approximation was used in the first part of the design method. The input latice parameters were obtained from the output of the computer program SYNCH [3]. The horizontal and vertical dispersion vectors (D_x,dD_x/ds,1) and (D_y,dD_y/ds,1), respectively, present general solutions of the inhomogenious Hill's equation of motion [2] when the horizontal and vertical motions are treated separately. A new vector (χ,ξ) was defined by Floquet's coordinate tranformation as:

$$\chi \equiv D/\sqrt{\beta} \equiv A*\sin\Phi \quad \text{and} \quad \xi \equiv D'\sqrt{\beta} + D\alpha/\sqrt{\beta} \equiv A*\cos\Phi, \quad ..(1)$$

where β,α, and Φ are the Twiss parameters [2]. A change of the vector amplitude "A" occurs only at the corresponding dipole (along the ξ-axis), while a propagation through all other elements is described with a change of the betatron phase Φ (see fig. 1). Correct positions of the vertical dipoles of the equal strength were very difficult to find due to dispersion dependence on the betatron functions (β_y and Φ), as well as due to the other constraints mentioned above. A satisfactory solution for the vertical overpass was found when the dispersion and the slope of the dispersion function were very close to zero at the end of the overpass.

The next step in the design was to use the solution obtained above as an input for the SYNCH [3] which calculated the lattice parameters of the whole ring with a closed orbit.

Theoretical Solution

A propagation of the vector (χ,ξ) through the new overpass is presented in figure 1. The dispersion vector at the vertical dipole which bends upward is parallel to the ξ-axis with a negative direction as the higher momentum particles are bent less.

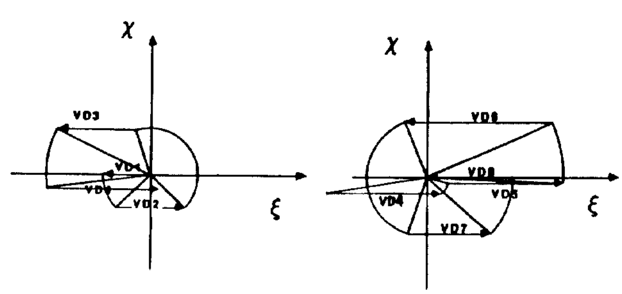

Fig. 1 Solution obtained by the thin element approximation. A propagation of the vector (χ,ξ) through the overpass.

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Figure 2 presents positions of the vertical dipoles in both DO overpasses.

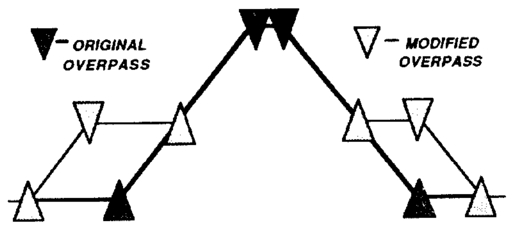

Fig. 2 Schematic presentation of the vertical dipole positions in the old (bold line) and new DO overpasses.

Figures 3 and 4 present the vertical dispersion function in the MR with the previous DO overpass and with the new DO overpass, respectively, excluding the other existing BO overpass. Both functions are obtained from the output of the SYNCH computer program.

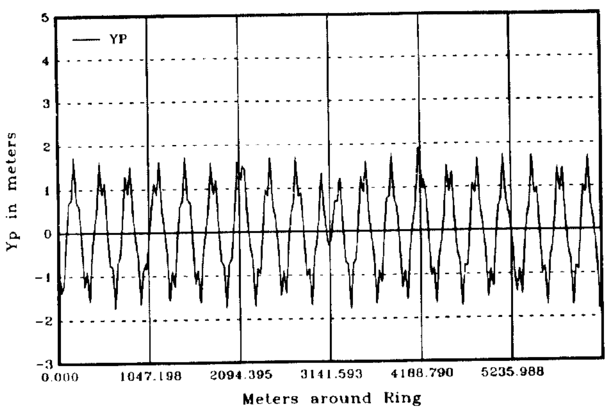

Fig. 3 The vertical dispersion function of the Main Ring due to the previous DO overpass (BO overpass is excluded).

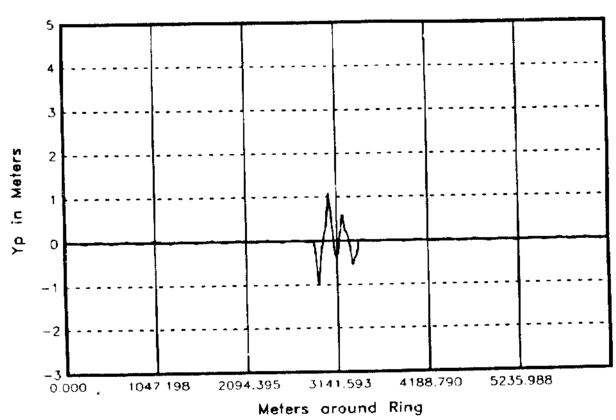

Fig. 4 The vertical dispersion function in the Main Ring due the new DO overpass (the BO overpass is excluded).

To lower vertical dispersion through the BO overpass and still keep the dispersion match between the MR and the TEV, higher values of the horizontal and vertical betatron tunes Q_x and Q_y were examined. When the tunes were raised from the designed and operating values of 19.4 up to 19.6 the dispersion through the BO overpass was lowered. The new DO overpass was shortened by one MR cell to provide a better overall solution with the tunes raised to values close to 19.6. This solution still provides the dispersion match between the MR and the TEV. The vertical dispersion of the new modified DO overpass when both the BO and DO overpasses are included is presented in figure 5. The function was again obtained from the output of the SYNCH computer program.

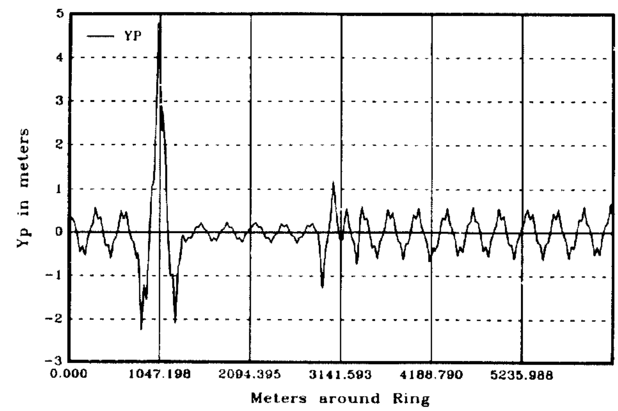

Fig. 5 The vertical dispersion function of the Main Ring when both BO and DO overpasses are included.

Experimental Measurements of the Vertical Dispersion Function

The results from the theoretical design of the overpass were implemented in the technical design. The new DO overpass was built within 10 weeks within the accelerator shutdown period between February and April of 1988. The start-up of the MR was very successful. The vertical dispersion in the Main Ring was measured before and after the new overpass was built, this is presented in figures 6 and 7, respectively. The dispersion function was measured from the difference in the vertical positions of the beam with and without a momentum offset.

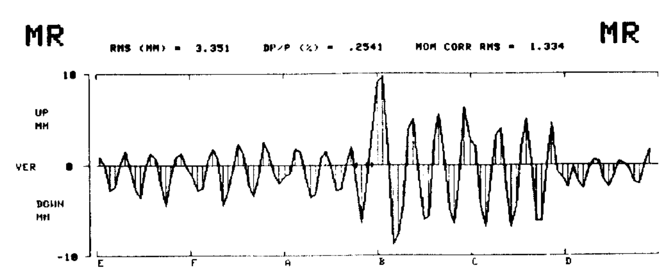

Fig. 6 Measured vertical dispersion function in the Main Ring with the old DO overpass.

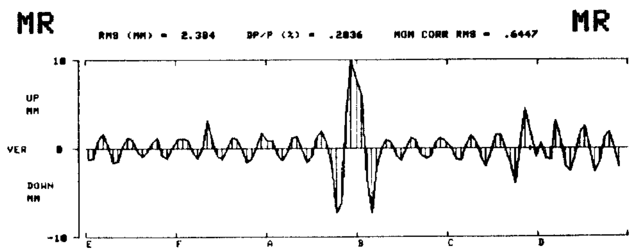

Fig. 7 Measured vertical dispersion function in the Main Ring with the new DO overpass.

The difference between 108 measured and predicted values can be used to form a distribution function. The mean value in this distribution was 0.014 meter while the standard deviation was 0.233 meters. The intensity of the beam in the MR was raised from 1.2 x 10^{12} to 1.8 x 10^{12} per batch which resulted in a much higher antiproton production rate (the highest production rates were over 2 mA/hour). The efficiency in the MR was raised from 85% up to 93%.

Measurements of the emittances in the MR before the extraction and in the TEV at the injection showed no emittance growth due to a mismatch. These measurements were performed with the "flying wire" system [4].

Conclusion

The start-up of the Main Ring with the new overpass was very smooth. The overpass was designed and built to lower the vertical beam size in the Main Ring by lowering the vertical dispersion function and to produce a dispersion match between the Tevatron and the Main Ring. A high degree of correspondence was obtained between the predicted and measured values of vertical dispersion around the whole Main Ring. The Main Ring performance improved considerably with respect to beam intensity (which was raised from 1.2 x 10^{12} to 1.8 x 10^{12} protons per batch) as well as with respect to the Main Ring overall efficiency (which was raised from 85% up to 93%).

References

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