DESIGN, INSTALLATION, AND COMMISSIONING OF THE DØ OVERPASS AT THE FERMILAB MAIN RING

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Abstract

In order to accommodate large detectors for p̄p studies at the Tevatron, the Main Ring has been modified to be non-planar. A 700 foot-long portion of the ring has been reworked to create an overpass which displaces the beam orbit upwards by 51 inches at the DØ long straight section.[1] The overpass region follows the "screw" geometry proposed by T. Collins.[2] A set of four vertically bending dipoles were inserted into the Main Ring lattice; they are powered on a separate bus and operate at twice the current and field level of a standard bend. To make space for these vertical bends, at each vertical bend point two of the four standard dipoles in a half-cell are removed and the other two are powered at twice the current and field level of the rest of the ring. The vertical bends also have a set of trim coils powered by a separate supply so that any difference in the horizontal and vertical bending strengths can be compensated.[3] The DØ overpass was commissioned with beam in November-December 1984. The principal effect on beam dynamics - predicted and observed - is the introduction of momentum dispersion in the vertical dimension of peak value 1.9m. To preserve closed orbit quality during acceleration, the vertical bends must track the rest of the ring with a precision of better than 0.1%. The Main Ring-Tevatron complex has now been running the fixed-target program for four months; the impact of the DØ overpass on accelerator performance has been minimal.

Design Considerations

The nominal separation between the beam orbit in the Main Ring and the orbit in the Tevatron is 25.5 inches. Early in the design study of a detector that would utilize the Tevatron as a p̄p collider, it was apparent that a larger separation at the detector was highly desirable. In 1981, T. Collins[2] proposed a specific lattice geometry in the Main Ring for achieving larger separation, called "the screw beam." His proposal increased the separation between the two machines to 21 feet in the region of the BØ detector. By very judicious placement of the vertical bends the vertical dispersion outside the overpass was kept to less than 0.5m, although its maximum value inside the overpass region exceeds 5m. His design called for only the vertical bending dipoles to be rolled to create an inward distortion in the orbit through the overpass region. This reduced the path length through the overpass to compensate for the increase in path length caused by the vertical distortion. Several months of careful, intense, theoretical study[4] followed. These confirmed the feasibility of the Collins overpass design and it was firmly incorporated into TeV I plans.

Then, in 1983, the new DØ experiment was approved. Since DØ was supposed to be a low budget compliment to BØ (CDF), it was clear that it would be difficult to get money for a 21-foot overpass involving modification of 1/12 of the Main Ring. A much reduced version of an overpass (nicknamed the Wildman's Dream) was described by Ohnuma.[5] This design for a 51 inch change to the Main Ring at DØ had the virtue of not requiring any modification to the tunnel, counter-balanced by the vice of creating vertical dispersion around the entire ring of up to 1.9m. After much calculation, it was decided to install WD51 with the caveat that if the machine did not work afterwards we could always restore the previous Main Ring orbit. It was also felt that if the accelerator worked with the DØ overpass, the BØ one could do no further harm.

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The DØ Overpass Geometry

The basic geometry of the overpass now installed at DØ utilizes the screw geometry as proposed by T. Collins, but ignores the condition $\Delta\psi = 360°$. One of the boundary conditions imposed was that the existing tunnel (outside of the DØ straight section) not be disturbed, a condition that limits the vertical displacement of the beam at DØ to ∿50 inches.

Once the sequence of the magnets and the overpass height are chosen, the detailed magnet positions are determined by a computer program which transports the beam element-by-element through the overpass. The magnet sequence for the DØ overpass is given in Fig. 1; it extends from the first bend downstream of the C46 quad to the bend just upstream of the D14 quad, a distance of 786 feet (3.8% of the accelerator circumference). The overpass geometry currently in place at DØ has vertical and horizontal projections of the overpass orbit shown in Fig. 2; the distances shown are actually path lengths along the orbit from bend centers.

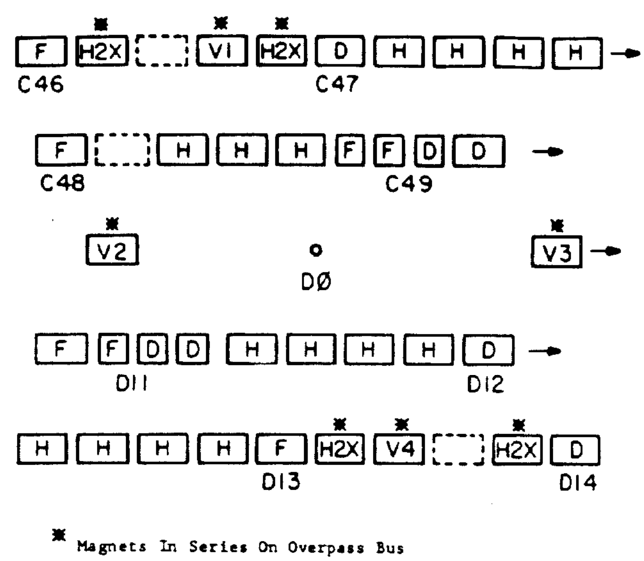

Figure 1. Magnet sequence in the DØ overpass.

There are 33 main magnets, (Fig. 1) 23 bend magnets, and 12 quads in the overpass region. Of these 33 magnets 29 have a common non-zero pitch and the four VB's have a roll of 1/4 radian. As indicated, the pitch angle, δ, of the beam and hence of the quads also, is 15.76 mrad. The dipole pitch is given by $\delta = \delta/\cos\phi/2$, where ϕ is the bend angle of a dipole, hence δ' differs from δ by one part in 3×10^4, which is much smaller than achievable setting errors of the dipoles. For a 239-inch long dipole the pitch

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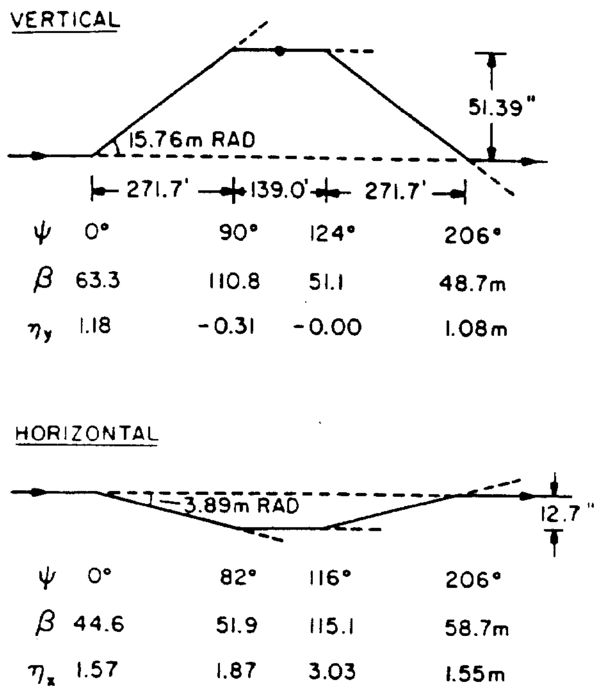
Figure 2

DØ OVERPASS - WD51(D2)



amounts to a 3.766 inch change in elevation from end to end and for a 7 foot quad a change of 1.324 inches. Pitch angles were set with a precision of ±0.08 mrad. The design roll angles of the VB magnets are ($\vec{B}$ w.r.t. the horizontal):

BV1	BV2	BV3	BV4
0.24150	-0.24150	-0.24291	0.24170 rad

The roll angles on the vertical bends were set to ±0.25 mrad and for the other magnets to ±0.5 mrad.

DØ Overpass Commissioning

Commissioning of the DØ overpass began in November 1984. On November 19 single pass beam traversed the overpass for the first time and later that same day coasting beam was achieved. On the next day protons were accelerated to 150 GeV. The overpass design assumes that the eight bend magnets on the overpass bus have precisely twice the bend angle of a standard Main Ring dipole. The four purely horizontal bends are standard B1's and B2's; operation at $2\times I_{MR}$ does not guarantee exactly twice the bend angle due to remnant field effects at 9 GeV (800 gauss) and saturation effects at 150 GeV (13.5 kG). The four vertical bends have substantially different geometry of coil and iron core, and are made from a different type of steel; hence, one might anticipate even larger deviations here. These are the reasons for the trim bus on the vertical bends and the two programmable currents in the power supply system.

Initially the tune up of these two waveform generators (henceforth called the Main and Trim) was difficult. The data from the vertical closed orbit is insufficient to distinguish between momentum errors and errors in either of the two supplies. The effects of the supply variations (particularly the Trim) on the horizontal data is small. Fortunately, during the same accelerator shutdown in which the overpass was installed, the Tevatron-style Beam Position Monitoring system was installed into the Main Ring. This system can simultaneously measure the horizontal and vertical closed orbit. An algorithm was developed which uses this data to determine the errors in momentum and overpass supply currents. The algorithm minimizes the following expression:

$$m = \frac{1}{2}\left\{\sum_{i=1}^{108}\left(x_i-\eta_{Hi}\delta_0-M_{Hi}\delta_M-T_{Hi}\delta_T\right)^2 + \sum_{i=1}^{108}\left(y_i-\eta_{Vi}\delta_0-M_{Vi}\delta_M-T_{Vi}\delta_T\right)^2\right\}$$

where the quantities are defined as follows:

- x_i, y_i - measured closed orbit, horizontal and vertical at the ith location.
- $\delta_0=\Delta P/P$ - fractional momentum deviation.
- $\delta_M=\Delta M/M$ - fractional deviation in main power supply current.
- $\delta_T=\Delta T/T$ - fractional deviation in trim power supply current.
- η_{Hi} - horizontal momentum dispersion function determined from ideal geometry.
- M_{Hi}, T_{Hi} - horizontal orbit distortion functions resulting from δ_M and δ_T, that is the changes in the orbit from changing the supplies are $\Delta x_i = M_{Hi}\delta_M$ and $\Delta x_i = T_{Hi}\Delta_T$.
- η_{Vi} - vertical momentum dispersion function.
- M_{Vi}, T_{Vi} - vertical orbit distortion functions resulting from δ_M and δ_T. In this case $M_{Vi} = T_{Vi} = -\eta_{Vi}$.

The algorithm determines values of δ_0, δ_M, and δ_T which produce the smallest RMS in the input closed orbit data

These values are used to tune the waveform generators for the overpass supplies. Furthermore, these components of beam position are removed from the initial closed orbit data and a file of massaged data is then available to other orbit correction algorithms (i.e. dipole three bumps, quadrupole alignment) so that they will not be correcting for momentum or overpass errors.

The effect of the overpass on the performance of Main Ring has been minimal. Two rather different impacts will be mentioned. With the overpass the beam loss at transition has been more difficult to control. In addition to the large momentum spread at γ_t there are typically large coherent momentum oscillations. Because of the non-zero vertical dispersion this leads to vertical oscillations which can cause scraping within the narrow vertical aperture of Main Ring. This problem can be solved by improvements to the Main Ring low-level rf system to control the momentum oscillations.

The second problem was an operational one. The original waveform generators used to program the overpass supplies were not able to provide the flexibility needed by the Main Ring to perform its role as a Tevatron injector, p-bar factory, study environment for rf manipulations and so on. This problem has been rectified with new waveform generators.

Apprehensions involving increased horizontal to vertical coupling have not been substantiated.

Summary

The Fermilab Main Ring has been altered to a non-planar orbit geometry by the construction of an overpass which raises the orbit by 51 inches at the DØ straight section. The choice of the helical geometry in the overpass region simplifies the task of accurate magnet placement. The lattice functions of the ring are essentially unchanged with the notable exception of the appearance of vertical dispersion, which agrees well with calculation. The tracking between vertical and horizontal bends at the 0.05% level is accomplished by programming the currents in the two local overpass buses; the programs are established by means of a computer code which analyzes the measured closed orbit in terms of three calculated distortion functions.

Encouraged by the successful operation of the DØ overpass, the design of the BØ overpass, which is similar in concept but with four times the displacement, has been completed and is scheduled to be implemented by June 1986.

References

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