CONF-770313--100 1120

MEASURING THE APERTURE AND LOCATING BEAM OBSTRUCTIONS IN THE FERMI LAB ACCELERATOR

J. C. Cannon and C. W. Schmidt
Fermi National Accelerator Laboratory*
Batavia, IL 60510

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Abstract

A method which uses the coasting beam at the injection energy to scan the aperture in a large accelerator such as the Main Accelerator at Fermilab will be described. This scanning procedure serves two purposes. It provides a record of the aperture size around the entire accelerator which can be used for future reference and comparison. And it is highly useful in locating beam obstructions which may be caused by a collapsed vacuum chamber or some small object in the chamber to within a few meters. A high degree of accuracy has been achieved in finding and removing even very small obstructions. This method uses several computer programs, the main accelerator correction dipoles and beam position detectors, and some simple calculations.

Introduction

In order to achieve optimum performance from an accelerator, the useful aperture available to the beam must be kept at a maximum. For a large accelerator as at Fermilab, where the aperture is approximately 4 cm in height, 11 cm in width and 6 km in circumference, maintaining the aperture at or near maximum has required considerable effort and has resulted in some useful techniques for monitoring and detecting aperture restrictions.

Accelerator Components

The Fermilab main accelerator lattice is composed primarily of 84 normal cells. Each cell is approximately 195-feet long and is composed of a horizontally focusing quadrupole, four bending magnets, a horizontally defocusing quadrupole and four additional bending magnets (Fig. 1). The two magnets

Table I

Summary of Main Accelerator Components^{1,2,3}

Bending Magnet	B1	B2	
Length	239	239	in ²
Aperture	1.5x5	2x4	in ²
Turns	12	16	
Bending-magnet excitation	8 (Inj.)	400	GeV
Field	.39	17.8	kG
Current	97	4650	A
Focusing Magnet			
Length	84		in ²
Pole Shape	xy=1.35		in
Turns	16		
Focusing-magnet excitation	8 (Inj.)	400	GeV
Field gradient	±5.4	235	kG/M
Current	89	4350	A
Correction dipole magnets	Horizontal	Vertical	
Effective length	10.0	9.1	in ²
Aperture	1.9x5.4	2.4x4.2	in ²
Max. field (±5A)	±680	±430	G
Max. bending angle (8 GeV)	±0.58	±0.34	mrads
Max. Deviation (8 GeV) (195 ft. downstream)	±2.2	±1.3	in

- B1 B1 Bending Magnet
- B2 B2 Bending Magnet
- QF Horizontal Focusing Quad
- QD Horizontal Defocusing Quad
- HCD Horizontal Correction Dipole
- VCD Vertical Correction Dipole
- HPS Horizontal Position Sensor
- VPS Vertical Position Sensor
- RM Radiation loss Monitor

Typical Accelerator Lattice
Figure 1

before and the two magnets after each quadrupole have appropriate apertures to efficiently match the beam size (Table I). Immediately following a horizontally focusing quadrupole is a horizontal beam position sensor and a horizontal dipole correction magnet. Likewise, following a horizontal defocusing (ver-

tical focusing) quadrupole is a vertical beam position sensor and a vertical dipole correction magnet¹. When coupled with the quadrupole deflections the correction magnets are of sufficient strength to move the beam, at the injection energy of 8 GeV, across the aperture at the next similar magnet 195-feet downstream. Above each quadrupole is a radiation monitor⁴ to locate beam loss by detecting excessive radiation. All of these devices can be controlled or monitored from the Main Control Room through a computer interface system⁵.

Aperture Scans

Local beam bumps, (Fig.2) which are normally used for centering the injected beam, can be used for scanning and measuring the aperture. By slowly moving the

Local Bump Profile
Figure 2

*Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration.

MASTER

beam through the full range of the bump while plotting the beam position signal at the bump center versus the circulating beam intensity shortly after injection, the local width or height of the aperture can be measured and recorded (Fig.3). The size of the entire aperture

Local Aperture Scan
Figure 3

can be examined and recorded by extending this procedure around the accelerator for all local bumps. The narrow places can later be investigated carefully with beam or by physical inspection and possibly corrected. The recorded data is useful as a comparison to confirm that work on the accelerator has not reduced the aperture. To cover more of the aperture area vertical bumps may be combined with horizontal scans to move off the midplane.

Obstacle Search

Aperture scan plots would occasionally be observed that were exceptionally narrow or had large dips (Fig.4) indicating an obstruction in the vacuum chamber.

Obstacle in Aperture
Figure 4

Other indications of beam obstructions have been found by the radiation monitor⁴ observations while injecting and accelerating beam and from residual radiation surveys⁶ taken in the tunnel immediately following shutdown. Unexplained features in these plots warrant further investigation.

At one time these radiation plots provided the

principle means for locating obstructions but could only provide information to within one or two cells. Residual radiation remaining from intensive beam bombardment frequently failed to locate the obstacle to a specific magnet. Small objects indicate very little residual activity through the magnet steel and other activity, especially activity several magnets downstream produced by beam scattered from the obstacle, would mask finding the correct location. Under such conditions several magnets would sometimes be removed needlessly before the cause was found or abandoned in frustration.

From this earlier work a method developed which uses the injected coasting beam to precisely locate obstructions. A vertical bump covering three cells ("4"-bump) is adjusted until a horizontal bump scanning the area in question produces a plot with a suitable minimum in the intensity (Fig.4). The cell in which the obstacle exists can be located by using overlapping horizontal bumps covering the suspicious area. The horizontal bump with best sensitivity is adjusted until the beam intercepts the obstruction and the horizontal beam position sensors upstream and downstream are recorded. From this data the path of the beam through the cell and intercepting the obstruction can be determined. A simple algorithm relating the beam position at the upstream and downstream position sensors (Y_1, Y_3) to the position of the beam in the intervening defocusing quadrupole (Y_2) can be calculated from the quadrupole strength (Figure 5). For the Fermilab main accelerator this is

$$Y_2 = \frac{Y_1 + Y_3}{3.14} \quad (1)$$

Beam Path Through Normal Cell

$$\text{At Fermilab: } Y_2 = \frac{Y_1 + Y_3}{3.14}$$

Figure 5

Another path may be found by slightly changing the upstream or downstream horizontal bump and readjusting the beam until it intercepts the obstacle for different beam positions. This may be repeated several times and the crossing of the various paths will generally locate the obstruction to within a particular magnet (Fig.6).

Obstructions

Most of the obstructions have been stainless steel slivers or needle-like wires which come from cutting open the vacuum chamber (Fig.7). They are slightly magnetic and stand up in the bending field, possibly falling down and sometimes moving around when the field is off or reduced. Even though a single wire standing in the vacuum chamber is small and narrow it appears as a forest of wire to a beam trying to make thousands of traverses around the accelerator. These wires typically have a bend on top from having been

Locating Obstacle With Several Beam Paths

Figure 6

melted by the beam and are highly radioactive. Within minutes after intensive beam bombardment the activity, measured on the surface of the magnet, is 10 to 40 mrad and decays rapidly with a half-life of about 30 minutes.

Other obstructions have been due to partially collapsed vacuum chambers, debris from accidental breaks in the vacuum system, and from poor alignment of old and new installations. A partially collapsed vacuum chamber inside a magnet sometimes requires inspection through end windows while the chamber is under vacuum since the collapsed portion may tend to return to normal when at atmospheric pressure. However, at high intensities holes have been burned through such vacuum chambers.

References

1. H. Feng, E. Malamud, S. Mori, J. Schivell and R. Yamada, "System for Injection Study of the NAL Main Accelerator", 1971 Part. Acc. Conf., IEEE Transactions on Nuclear Science, Vol. NS-18, No. 3, June 1971, page 432.
2. H. Hinterberger, J. Satti, C. Schmidt, R. Sheldon and R. Yamada, "Bending Magnets of the NAL Main Accelerator", 1971 Part. Acc. Conf., Op. Cit., pages 853.
3. H. Hinterberger, S. Pruss, J. Satti, J. Schivell, C. Schmidt, and R. Sheldon, "Quadrupole Magnets of the NAL Main Accelerator", 1971 Part. Acc. Conf. Op. Cit., page 857.
4. R. A. Lundy and D. F. Sutter, "A System for Monitoring Proton Losses from the NAL Main Accelerator", 1973 Part. Acc. Conf. IEEE Transaction on Nuclear Science, Vol NS-20, No. 3, June 1973, page 596.
5. R. E. Daniels, R. W. Goodwin, and M. R. Storm, "NAL Computer Control System", 1973 Part. Acc. Conf. Op. Cit., page 505.
6. R. E. Shafer and D. D. Jovanovic, "Radiation Survey Vehicle for the NAL Main Ring", 1973 Part. Acc. Conf., Op. Cit., page 499.

Wire Obstacle Found at B16-4

Figure 7

Conclusions

Being able to accurately detect and remove aperture restrictions and obstacles has been extremely useful. The accuracy of this method has been high and aperture scans are routinely done.