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LAMBERTSON MAGNET DESIGN FOR THE TEVATRON EXTRACTION CHANNEL

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Abstract

The beam splitting requirements of the Tevatron extraction system necessitated the design of two different high field (11 kG and 15 kG) magnetic septa. We present details of the magnet design with emphasis of the construction techniques used to achieve good vacuum behaviour and septum straightness while maintaining magnetic field quality.

Introduction

The basic problem associated with the design of the Tevatron extraction channel was to provide sufficient separation between the circulating and extracted beam at 1000 GeV to allow the latter to avoid the downstream machine elements and enter the beam splitting stations in a manner compatible with the existing beam line tunnels. The available space for the Lambertson magnets is approximately 95 feet with the required beam separation at the downstream end 6 inches. This corresponds to an average field of 12.5 kG throughout the string of magnets. In attempting to design a suitable magnet it rapidly became apparent that even with high grade magnetic steel (Republic Steel "Locore B") it was not possible to provide the required dipole field while ensuring the remanent field in the field-free region was sufficiently small to produce a negligible effect on the circulating beam. The optimal magnet design in terms of field quality is given by a symmetric magnet (see Figure 1) but even with this form the maximum dipole field we could tolerate was ~11.2 kG.

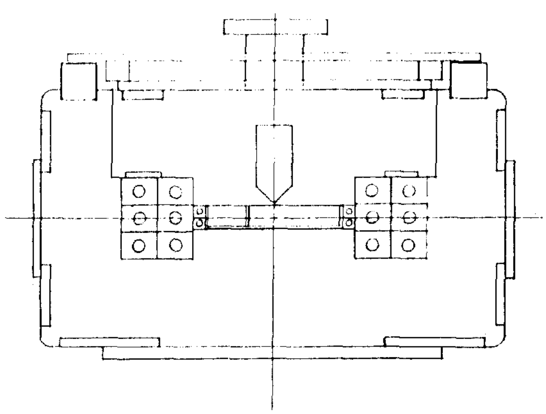

Figure 1

The solution we adopted was to use 3 of these symmetric magnets to provide an initial beam separation of ~2 inches, and the making use of this separation we designed a highly asymmetric magnet (see Figure 2) which generated ~15.5 kG dipole field downstream in the region of the extracted beam with a much lower field around the septum region.

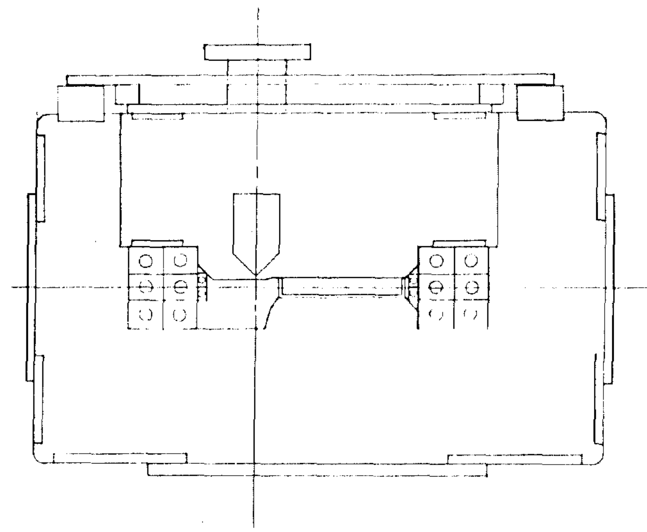

Figure 2

A special end design was also made to reduce flux leakage from the dipole field. Details of the field quality and magnet ends are being presented elsewhere in this conference[1].

The magnets are powered in series with the main Tevatron buss and thus to provide some independent field control each magnet is equipped with trim coils which allow the body field to be varied by up to 5% using an independent power supply.

The circulating Tevatron beam is only ~10.5 inches above the tunnel floor; consequently the magnets were designed to be self-supporting and rigid enough to hold the straightness tolerance of 0.015 inches along the septum. The desired vacuum in the region of the magnets in situ is 1×10^{-8} Torr (or better). We shall now examine in detail the techniques employed to achieve these goals.

The mechanical design of the six-inch symmetric Lambertson and the downstream extraction Lambertson followed similar design concepts to that of the injection Lambertson magnets. They were both designed with the outer U-shaped core very rigid so as to be self-supporting and very straight. The inner core which contains the field-free region and the dipole region was constructed by surrounding the laminations with a vacuum skin - beam pipe combination (see Figure 3). This 6 inch core was made somewhat flexible so that it would conform to the shape of the outer U-shaped lamination structure when they are assembled together. The inner core was made longer than the outer core and the vacuum-quick disconnect flanges that attached to the magnet were made out of steel instead of stainless steel in order to reduce the flux leakage from the dipole field (see Figure 4). In addition to the steel quick disconnect flange, a plate

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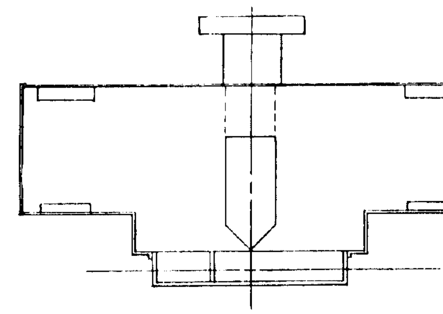

Figure 3

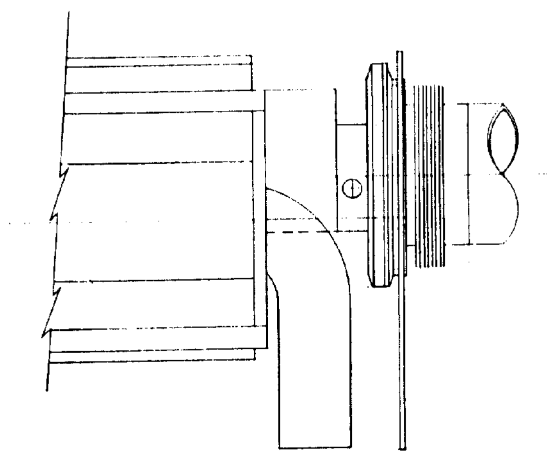

Figure 4

3/8 inch thick by 17 inches in diameter was located asymmetrically on the steel flange to add more shielding from the remanent fields generated by the coil cross overs.

As mentioned earlier, the vacuum requirement was $1x10^{-8}$ Torr or better. This was obtained by having the individual steel laminations and end plates baked in a vacuum oven at 800°C to eliminate the hydrogen in the steel along with any oils and water vapor. The laminations were then stacked on a clean stacking fixture using white gloves. Stainless steel tie bars were used to complete the structure. Next the lamination stack was removed from the stacking fixture and placed on a table where it received the stainless steel skin and beam pipe. After welding and helium leak testing, the entire structure was equipped with electric cal-rods and an outer wrap of insulation. The inner core structure was then heated to 380°C while being pumped by a rougher, turbo and cold trap combination. Vacuum pressures would typically go as high as $8x10^{-4}$ Torr at full temperature before slowly starting to decrease. At $2x10^{-5}$ Torr, the heat was turned off and the ion pumps which were mounted to the core as they would be in machine operation were turned on. If the ion pump pressure only reached $2x10^{-6}$ Torr, this meant that oil had come out of the stainless steel skins and tie bars and accumulated on the end plates of the core which were not being baked at 380°C due to the lead coated C-seals in the quick disconnect flanges. If this occurred, the core would be vented up using dry nitrogen and the end plates and associated parts cleaned of all oil and contaminates. The entire bake sequence would be repeated. With no oil present and the six ion pumps operating, vacuum readings would typically be $2x10^{-9}$ Torr after the core reached room temperature.

The coils for both magnets were constructed by first forming the end hair pin pieces around an internal winding fixture. Both cross over end sets were made in this manner. Next, using the winding fixture, the pieces between the end sets were measured, cut and brazed in place. De-keystoning, sandblasting and leak checking followed. After testing, the coils were wrapped with a double half lap of .007 B-stage glass tape with a double half lap of B-stage ground wrap. The coil was then bolted securely in the curing fixture and cured at 350°F. The small correction coils were made in a similar manner. Assembly of the outer core, coils and inner vacuum core took place in the following way. The outer core was placed on a table with the U-shape point up. G-7 insulation material was placed in the outer core to act as both a shim and as additional insulation. The coils were then lowered into the outer core and more G-7 was added to the top and inner side in order to completely enclose the coil in G-7. Next the inner core was placed on top of the outer core in such a way that it could be pressed into the outer core. By examining the detailed parts closely, one would see that a .010 air gap was left between the stainless steel skin and the outer core. After pressing the two cores together, a backing plate was placed across the inner core and by securing it to the upper sides of the U-shaped outer core, the inner core was pressed firmly into its final position so that it would conform to whatever shape the outer core takes on.

Straightening of the magnet was the next step in construction. This was accomplished by placing the magnet on stands in the same orientation as it would be in the 1 TeV machine. The outer core of the magnet was surveyed and the data plotted. By looking at the curve generated by the survey data, welds were placed across the magnet to counteract the high and low points of the plot. This procedure was repeated until the magnet reached a desired straightness. In general, the outer core was made straight enough that the curve generated by the survey points would fit in a .010 envelope. With this degree of straightness on the outer core, the inner core's pole face would fit in the envelope of .015 inches. These tolerances were adequate for the 1 TeV extraction channel.

The last steps in construction were to manifold the coils for water and electrical connections, weld the upper portion of the stands to the sides of the magnet, and lastly, paint the magnet with heat resistant paint so that recovery bakes of 100°C which would take place in the machine operation would not effect the magnet and protect the magnet from corrosion.

References

1. F.A. Rad, "Field Shaping of Lambertson Magnets", this proceedings