© 1993 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

The Mechanical Design of a Bunched Beam Stochastic Cooling Tank for the FNAL Tevatron

P. Hurth, G. Jackson
Fermi National Accelerator Laboratory*, Batavia, Illinois 60510

Abstract

The stringent alignment required for successful bunched beam stochastic cooling in FNAL's Tevatron necessitates the design and manufacture of a complex vacuum compatible mechanical alignment system. The design presented uses remote motion control to provide a positioning system with four degrees of freedom for placing two symmetric pickup loop arrays about the proton beam and with two degrees of freedom for aligning the arrays relative to each other. The system provides a 7.62 cm aperture between arrays during injection and a 1.90 cm aperture during operation while maintaining alignment between arrays within 50 μm. The system also allows precise remote longitudinal adjustment between pickup arrays with .002 μm resolution via a piezoelectric crystal inchworm motor in vacuum. Discussion includes the manufacture and installation of four complete pickup and kicker systems in the FNAL Tevatron.

I. INTRODUCTION

Stochastic cooling of proton and antiproton bunched beams in the Tevatron requires the careful design of a precise alignment and positioning system for the proper placement of two microwave loop arrays (per tank) symmetrically about the circulating beams. This high level of symmetric alignment is necessary to achieve the stringent electrical balances required to successfully filter out common mode noise [1]. The precision alignment criterion in addition to the requirements of vacuum compatibility, smooth electrical transitions of beam tube current through the tanks, and actual physical size constraints post severe design challenges for the mechanical engineering design of the tanks.

A. Positional Alignment and Movement Criteria

The loop arrays for both kicker and pick-up tanks are constructed of flexible, glass impregnated PTFE circuit board attached to stiff, flat aluminum backing plates. During operation, the array plates are ideally located symmetrically on either side of the beam, each at a distance of 9.5 mm from beam center. The absolute distance between the arrays is not crucial (+/- 2.5 mm) provided the arrays can be centered on the beam symmetrically within 0.13 mm. In addition, during beam injection into the Tevatron, the array plates must allow for a physical beam line aperture of 7.62 cm. Thus the criteria for array plate motion is set at 0.13 mm resolution and at least 2.86 cm travel per plate perpendicular to beam axis.

The alignment of paired array plates to each other is also of great concern. The plates should be flat within 50 μm and parallel to each other within 0.5 mm. Locationally, the centerline of the planar loops on each array plate must be aligned parallel to the loops on the facing plate, and the beam axis, within 0.5 mm.

The longitudinal alignment (along beam axis) of the array plates to each other is of primary importance in the pick-up tanks because any small misalignments could produce unsymmetric signal delays causing errors in common mode rejection [1].. Requirements for alignment in this direction are not precisely known due to the uncertainty of the effect upon the filtering electronics, however real time remote control of the longitudinal position of the boards with a tight resolution of approximately 1 μm should alleviate any problems associated with longitudinal misalignment.

The precise alignment required at the operating aperture should also be repeatable within 50 μm after the array plates are cycled through the entire aperture range necessary for injection. This positional repeatability will allow the cooling system to come back up on line as soon after injection as possible without any delays for realignment.

Finally, the entire array assembly of each tank should possess the capability to be remotely positioned relative to the beam so that errors from the theoretical (surveyed) beam center to actual beam center can be zeroed out easily during initial operation. This requires alignment drives to position the tanks horizontally and vertically plus rotationally about the vertical and horizontal axes (pitch and yaw) with a resolution of 0.13 mm and travel of at least +/- 1.3 cm.

B. Other Design Criteria

In order to reduce unwanted higher order microwave modes created by the bunched beam image current discontinuities, it is necessary to provide a smooth transition path for the current from the upstream beam tube to the ground plane of the loop arrays and back to the downstream beam tube. In addition, the design of the tank should incorporate microwave absorbing material surrounding the beam line in an attempt to damp out any microwave ringing caused by the effective cavity of the interior surface of the surrounding vacuum tank.

The locations of the bunched beam stochastic cooling systems in the Tevatron pose great limitations on overall tank dimensions. The limiting dimensions for one tank (pick-up or kicker) are 56 cm in the vertical and horizontal directions and 140 cm in the longitudinal (beam axis) direction with a beam line center height of 26.7 cm.

Lastly, the materials and design of both pick-up and kicker tanks should be vacuum compatible since they are installed directly into the Tevatron's vacuum system. The requirement for vacuum in the Tevatron is less than 10^{-8} torr.

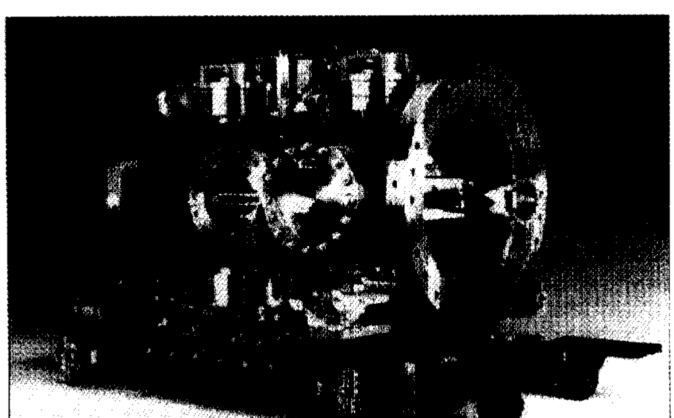

Figure 1. Vertical Cooling Tank on Stand.

* Operated by the Universities Research Association under contract with the U.S. Department of Energy.

II. DESIGN AND CONSTRUCTION

Both pick-up and kicker tanks are constructed of a stainless steel (304) 30.5 cm diameter tube capped on both ends with 35.6 cm diameter conflat type vacuum flanges. The central tube portion is modified to provide flat surfaces for the array insertion drives and to comply with physical size constraints (see fig. 1 & 2). Additional feedthrough ports are provided around the entire periphery of a tank for electrical connections, ion pumps and the array insertion drives. The entire length of a tank, including dog-leg bellows at either end to allow for remote tank motion, is 110.5 cm.

A. Array Insertion and Longitudinal Drive Systems

In order to facilitate the range in aperture required for operation and injection, a plunging-type insertion drive system for the array plates is utilized. Although this type of design, which allows for relative motion between the two array plates, inherently introduces clearances and therefore increased tolerances into the alignment system, it is necessary to allow the capability of signal amplitude adjustment, via adjusting each plate's distance from the beam.

Each 15.2 cm by 38.1 cm aluminum array plate of each tank array plate pair is inserted via a dedicated independent drive. However, each array plate is also registered to its mating plate through tightly toleranced stainless steel guide shafts. Figure 2 shows a cross-section of an insertion guide shaft and drive assembly. Clearance between the guide shaft and mating bushing is 25 μm. The guide shaft is coated with 38 μm of a PTFE based surface coating, to reduce friction and eliminate galling in the sliding connection.

The array plates are registered to each other in two locations, near the upstream and downstream edges of the array plates. This arrangement ensures the even and stable motion of the arrays relative to each other. In order to alleviate binding due to the overconstraint of using two full guide shafts, the upstream guide shaft has a full circular cross-section to register the plates positionally while the downstream guide shaft has a diamond shaped cross-section, oriented perpendicular to the beam line (so that only two opposite sides of the shaft contact the bushing wall), to register the plates rotationally. In addition, to allow relative motion between the guide shaft locations, the downstream guide shaft and bushing are connected to their respective array backing plates with a belleville spring loaded connection plate. This special connection plate allows longitudinal slipping to occur during the 150°C vacuum bake-out without losing rotational alignment.

Linear motion is transferred from the exterior of the tank to the interior array plates via a conventional welded bellows feedthrough. On the atmosphere side, a lubricated bronze bushing is used to locate the guide shaft/array plate assembly relative to the vacuum tank (see fig. 2). Actual linear motion is achieved by exterior mounted worm drive assemblies and low friction ball screws driven by a standard DC stepping motor. Backlash associated with the worm drives is virtually eliminated by the pre-loading effect of the vacuum pressure. Each drive assembly is mounted within a vacuum flange for easy assembly.

Initial alignment and registration of each pair of array plates is achieved before assembly by pinning the array plates together with an alignment fixture. The alignment fixture is removed only after the array plates have been securely mounted within the tank to the insertion bellows. The same alignment fixture is used for surveying the precise location of the array plates to exterior mounted tooling balls.

Submicron longitudinal alignment of the pick-up tank array plates, relative to each other, is achieved through the use of a piezo-electric crystal motor. This motor utilizes an inchworm type series of crystal expansions and contractions to move one array with respect to the other. In figure 2, the top array plate is actually mounted (hung) beneath a second aluminum plate. This guidance plate is attached rigidly to the insertion drives and provides mounting positions for three small, Teflon-S coated, guide shafts. Bushings attached to the top surface of the array plate mate (with 38 μm clearance) to the shafts on the guidance plate to allow longitudinal motion of the top array plate relative to the guidance plate (and lower array plate). The motion is provided by the inchworm motor which rides on a ceramic shaft also mounted on the guidance plate. The inchworm motor (made by Burleigh Instruments [2]) is only capable of 1.5 kg of load, so the entire drive system is tweaked manually until the top array plate glides effortlessly on the guidance plate's mounted shafts.

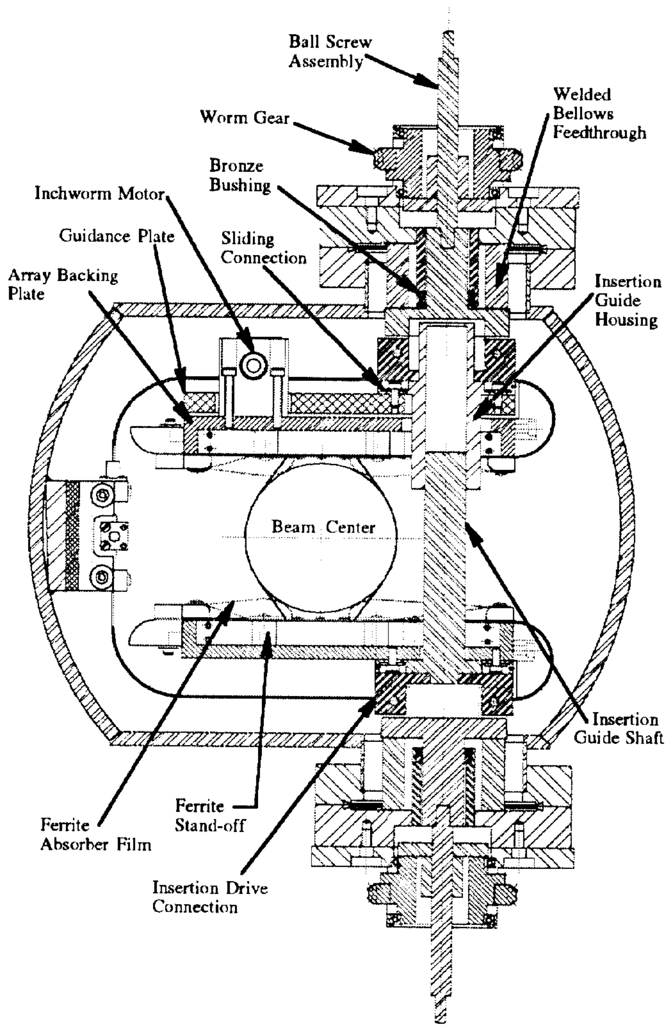

Figure 2. Cross-section view of array insertion drive assembly.

B. Array Board/Absorber Design

The loop array circuit boards are connected to the aluminum backing plates via several ferrite absorber standoffs. These standoffs help eliminate unwanted microwave ringing in the concave area created between the array backing plates and the backs of the array circuit boards (see fig. 2). To damp out ringing created by the cavity of the tank itself, loops, or pillows, of carbon coated polyimide film were attached to the array boards on each side of the pick-up/kicker loops (see fig. 2). These loops of film fill the gaps between the faces of the loop array boards when the boards are at the narrow aperture required for operation.

Smooth electrical transition from the up and downstream beam tubes to the array boards is achieved by the use of beryllium-copper foil (0.25 mm thick) and commercially available Be-Cu finger stock. The foil is formed into a transition piece with a cylindrical shape on one end and two flat tabs on the other (see fig. 3). The cylindrical end is outfitted with the fingerstock and fitted into a neighboring beam tube and the flat tabs are fastened tight to each loop array ground plane. The fingerstock keeps positive spring loaded pressure on the interior wall of the beam tube for good electrical transmission without hindering the array plates' insertion movements.

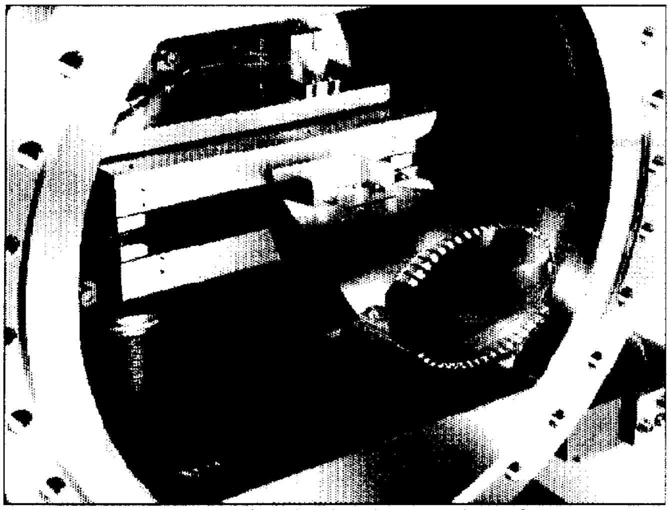

Figure 3. Interior end of tank, showing transition foil assembly.

In the pick-up tanks, the transition pieces are modified to accommodate the longitudinal motion of the inchworm drive system. Figure 3 shows the modification, a sliding interface foil tab and mating aluminum housing, designed to provide a smooth transition for the image current while allowing array longitudinal movement.

C. Vacuum Design

All materials used in the design of the bunched beam cooling tanks are vacuum compatible. Materials include 6061 aluminum, 304 stainless steel, beryllium-copper foil, PTFE surface coating, glass impregnated PTFE circuit board, polyimide film, and high absorbtion nickel ferrite. All blind holes and trapped volumes are vented to ensure quick pump down. Stainless steel screws which engage stainless steel threads are gold plated to avoid galling. All stainless steel is degassed at 850^{0}C to remove the hydrogen content before machining. An additional 150°C bake is performed on the installed tanks to remove any water content adsorbed during installation. Two 20 l/s diode pumps are used on each tank to achieve an ultimate pressure of 10^{-9} torr.

D. Tank Stand Design

The geometrical space constraints of the Main Ring tunnel required the design of two separate stands. One for tanks oriented for stochastic cooling in the vertical direction and one for tanks oriented for cooling in the horizontal direction. Both designs use conventional gear and sliding v-block designs driven by standard DC stepping motors to achieve remote motion in four degrees of freedom. The stands are capable of tranlations perpendicular to the beam line in the vertical and horizontal directions and rotations about the horizontal and vertical axes. Detailed discussion of these stand designs is beyond the scope of this paper, suffice to state that the stand designs satisfy the travel and resolution requirements described earlier to initially align the array assemblies with respect to the actual beam centerline.

III. DESIGN RESULTS

Table 1 shows the results of the described tank design in terms of alignment parameters. All motions desired are provided at the resolutions, tolerances, and repeatability required for successful bunched beam cooling.

After the construction of one prototype tank of this design, it was noted that the inchworm motor guides were binding intermittently, especially after the 150° vacuum bake-out. After careful analysis, it was determined that the array plate and guide shaft assembly was coupled to the vacuum tank walls to a greater extent than predicted. The vacuum tank wall deflections due to vacuum pressure loading (0.20 mm) was enough to cause binding in the close fitting inchworm motor guides. In order to decouple the interior assembly from the exterior vacuum jacket, the bronze bushings in the bellows assembly have been removed. This results in allowing the interior components to keep their close alignment by floating with respect to the exterior vacuum tank walls. The locating function of the bronze bushings was found to be redundant since the clearance on the ball screw drives is much tighter than previously perceived (within 50 μm). In addition, the transition foil sliding connection shown in figure 3 was redesigned to decrease the friction loading on the inchworm motor. The redesign incorporates a flexible foil tab to allow longitudinal inchworm motion. These changes result in a free moving inchworm drive system even directly after the 150°C bake-out.

Alignment Parameter	Required Value	Actual Value Achieved
Array Insertion Drive		
Travel	2.858 cm	2.858 cm
Resolution	0.127 mm	5.3 E-4 mm
Repeatability	50.8 μm	50.8μm
Longitudinal (Inchworm) Drive		
Travel	+/- 1.6mm	+/- 3.2mm
Resolution	1 μm	2 nm
Repeatability	NA	NA
Array Plate Relative Alignment		
Parallel (XZ)	0.508mm	0.279mm
Parallel (YZ)	0.508mm	0.152mm
Location (X)	+/-0.127mm	+/-0.076mm

Table 1. Critical Alignment Criteria Satisfaction.

The design described here has been built and tested in prototype form successfully. All drive systems move smoothly and with the tolerances, resolutions, and repeatability required. Presently four complete systems (8 tanks total) are being constructed and should be ready for installation in the FNAL Tevatron during the 1993 shutdown.

IV. ACKNOWLEDGMENTS

The author would like to thank the following FNAL personnel who contributed to the design and construction of the Tevatron bunched beam stochastic cooling mechanical tank system: L. Brown, R. Brown, J. Budlong, D. Cobb, C. Foster, H. Gusler, R. Joseph, H. Landers, N. Lesnieski, J. Misek, D. Poll, D. Snee, M. Tarkowski, and G. Waver.

V. REFERENCES

[1] G. Jackson, et al., "Bunched Beam Stochastic Cooling in the Fermilab Tevatron Collider," these proceedings.

[2] Burleigh Instruments, Inc. Burleigh Park, Fishers, New York 14453.