ROBUST MECHANICAL DESIGN FOR RHIC TRANSVERSE STOCHASTIC COOLING PICKUP

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Abstract

The RHIC transverse Stochastic Cooling Pickup uses a pair of high resolution 4-8 GHz frequency band planar loop arrays to measure the Schottky signals from the bunched beams in the two transverse planes of the two rings. Precision alignment between the two 381 mm long array boards was achieved by surveying two specially designed alignment fixtures outside the vacuum chamber and using a pair of high resolution, motor controlled, and force balanced actuators. Robust mechanical design was achieved by excluding wearable mechanical joints and fragile electronics inside the vacuum chamber. Both mechanical designs and structural analysis results, for the vacuum chamber and for the array board supports, are presented. Two horizontal and two vertical plane pickups have been fabricated and installed in RHIC for the FY2012 run. Successful performance has been reported.

INTRODUCTION

The injected ion beams inside the two RHIC rings have a typical bunch rate of 10 MHz with 5 ns in length. The number of particles per bunch varies from 2 x 10^8 (for uranium) [1] to 1.5 x 10^9 (for gold) [2]. Due to intra-beam scattering (IBS), beam emittance would grow and reduce the intensity and the lifetime of the beam. RHIC has been successfully applying the stochastic cooling technique to correct this problem in the past 10 years. Based on the experience, a new transverse stochastic cooling system, which includes a broad band pickup and a kicker, has been developed recently. This paper will focus on the mechanical design of the new pickup.

McGinnis (1991) [3] developed a 4-8 GHz bandwidth bunched beam Stochastic Cooling Arrays for the Fermilab Tevatron. Due to the strong coherent frequency components presented in the high frequency bunched beam, the common mode Schottky signals from the two planar loop couplers must be subtracted before taking the measurement, which requires a high precision and repeatable mechanical alignment between the two arrays [3]. Hurh (1993) [4] designed a bunched beam Stochastic Cooling Tank for the FNAL Tevatron, which integrated the loop arrays into a vacuum chamber. The arrays were driven by two stepper motors through two guided plungers, which could provide different apertures for the changing beam size. Hurh's original design, however, has a few disadvantages, which include (1) The Teflon coated array board guiding shafts and the piezoelectric crystal inchworm motor could get stuck in vacuum, (2) The two pieces design BeCu image current transition assembly could buckle and reduce the aperture unexpectedly, and (3) The BeCu spring fingers on the image current transition assembly could lose their elastic strength and the contact forces on the beam pipe after the vacuum bake out.

Wei (2004) [5] applied the coasting beam theory and demonstrated that a 3-D stochastic cooling system with a 4-8 GHz bandwidth could effectively counteract IBS in RHIC. The 4-8 GHz Bunched Beam Stochastic Cooling Arrays, which were developed by McGinnis, were therefore adopted and retrofitted to become the sensor in the new pickup design. The newly developed transverse stochastic cooling pickup has addressed all the mechanical problems described above. Both mechanical designs and the supporting structural analysis results are presented below.

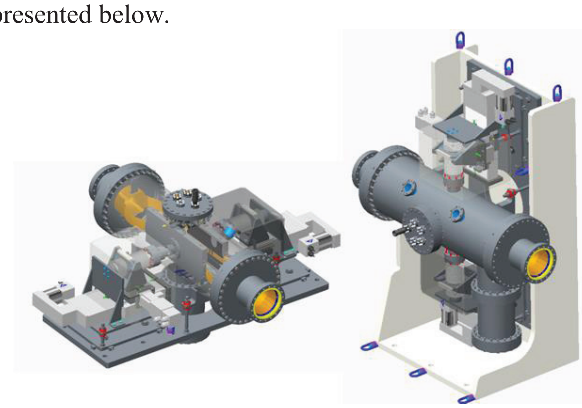

Figure 1: Horizontal and vertical stochastic cooling pickup.

MECHANICAL DESIGN OF THE TRANSVERSE STOCHASTIC PICKUP

The transverse stochastic cooling pickup could be installed either horizontally or vertically (see Fig. 1) to measure the Schottky signals from the RHIC bunched beam in the corresponding planes. The pickup integrates a pair of printed planar loop arrays, produced by Fermilab [3], with two aluminum backing boards being retrofitted into the newly designed UHV chamber. Two pickup leads and a proximity sensor (which is a pair of gold plated SST spring fingers, made by Lairtech) are provided on the two 381 mm x 152 mm x 17.5 mm array boards. Each array board is cantilever supported by a motor controlled precision linear stage, which is mounted on a four axes (X-Y-Z-theta) adjustable table. The linear stages provide a fine tuning on the relative alignment between two array boards in the X and the Z (or beam) direction. The alignment accuracy between the two array boards is required to be maintained within 50 microns

*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.

during the operation. Apertures between the two pickup arrays are 0.7” (18 mm) and 3.5” (89 mm) for the operation and the standby positions respectively.

Precision Alignment between Array Boards

Precision alignment between two loop arrays was achieved by accurately monitoring the array positions, using the laser survey technology, and by using motor controlled high precision actuators to drive the array boards. To monitor loop array positions without breaking the vacuum, two special external alignment fixtures (Fig. 2) have been designed and installed on the mounting stages. Each fixture has four targets on the four corners. The distance between two targets was chosen to be the same as the plunger length so that one could measure the misalignment directly on the fixture. To position the array boards accurately, two high precision AeroTech Stages (AST150-100), with a stroke of 1.8” (46 mm), are used to drive the array boards perpendicularly to the beam direction through two rigid plungers (see Fig. 1). One of the AST150-100 stages is stacked with an AST100-050 stage, with a +/- 1 mm adjustment, to provide a longitudinal (or beam) direction adjustment. Both AST150-100 and AST100-050 have a resolution of 0.5 microns with a position accuracy of better than 5 microns. An alignment accuracy of ~15 microns is achievable between the two array boards. All the stages were custom retrofitted with a ‘Home’ position at the middle of the stroke. Two welded bellows (Standard Bellows SBC 300-200-3) were installed on both sides of each actuator stage to balance the vacuum forces on the stage.

Figure 2: External array board alignment fixtures.

Signal Feedthroughs and Cable Strain Relief

To seek for a more reliable RF feedthrough design, two types of signal feedthroughs were developed and tested on the pickup device for the comparison. One is a custom design and was fabricated by INTA Technologies, which provides the vacuum seal by brazing the alumina insulator onto a kovar center conductor (Fig. 3(A)). The other one is designed and made by SRI Hermetics (SRIVF102), which used the glass seal technology to seal a copper center conductor and a stainless steel housing (Fig. 3(B)). The former has a higher bake out temperature of 300°C and the latter gives a broader bandwidth. Both designs have a reasonable high yield.

To provide a strain relief to the unsupported cable, between the feedthrough and the array board, and to provide the vacuum seal, a dual purpose custom made copper gasket (made of 1/4 hard oxygen free copper) was also developed (Fig. 3(C)).

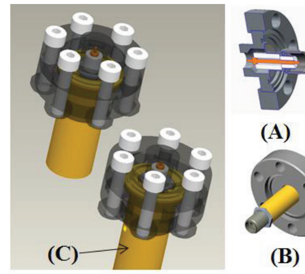

Figure 3: (A)INTA feedthru, (B) SRI feedthru, and (C) dual purpose copper gasket.

Long Lived Image Current Transition Piece

Image Current Transient Pieces (ICTP), which bridge the array boards and the beam pipes, are required to eliminate the excitation of the high-order resonant modes. To accommodate the aperture variations and to have a long service life, a special ICTP had been developed. Each ICTP includes a flexible 13 x 48 x 0.25 mm thick beryllium copper (C17200 Alloy 25) strip and a rigid copper plated 0.76 mm thick stainless steel structure (see Fig. 1), which has a rectangular opening on one end and a circular opening on the other end. Copper plated SST spring fingers are installed on the circular end, which are secured by a stainless steel spring ring, to provide a positive contact to the beam pipe. The stainless steel structure and the spring fingers are bakable to 300°C without losing their elastic strength. Fatigue test result, with repetitive bending between the minimum and the maximum aperture, demonstrated that the life time of the beryllium copper strip could exceed 10 k cycles without a failure, which is far beyond the application.

Maintenance Free Vacuum Design

Materials inside the vacuum chamber, which include stainless steel, copper, carbon coated polyimide, ferrite and aluminum are low outgassing. Vacuum components were cleaned and baked at 450°C for the stainless steel material and at 150°C for other materials before the installation. Venting holes were provided for all the trapped volumes. Stainless steel bolts were silver plated to avoid galling in vacuum. A vacuum pump (SAES Getters Model 4H0426) is installed underneath the vacuum chamber to maintain an UHV inside the chamber. There are no wearable components inside the vacuum chamber.

STRUCTURAL ANALYSES

Stage Linear Bearing Lifetime Analysis

The load distributions on the actuator stages were carefully planned and analyzed to increase the lifetime of the stage linear bearings. Figure 4 shows the actual stage loads vs. load capacities at the calculated CG locations and the expected travel life time for the stage bearings.

ISBN 978-3-95450-138-0

The results show that the travel lifetime with the current design would be no less than 2.3 x 10^9 mm.

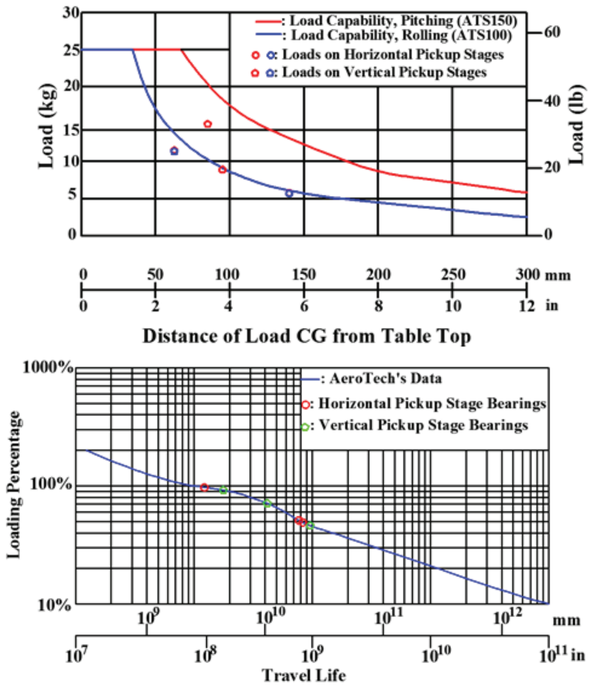

Figure 4: Actuator stage loads and stage bearing lifetime.

Support Structure Stress Analysis

The horizontal and the vertical stochastic cooling pickup assemblies have an overall weight of 193 kg and 315 kg respectively. When the chamber is in vacuum, a pressure load of 15 psi is applied on the surfaces of the chamber. All the components, except the pickup device and the supporting plates (which are made of aluminum), are made of 304 stainless steel. Stress analysis results, using ANSYS, showed that for the worst case when the pickup is supported vertically, the maximum stress and the maximum deformation on the support structure, due to the loads described above, are 6019 psi (41.5 MPa) (with a safety factor of 5 to yield) and .007” (0.18 mm) respectively (Fig. 5). The results have confirmed the structural stability of the pickup design.

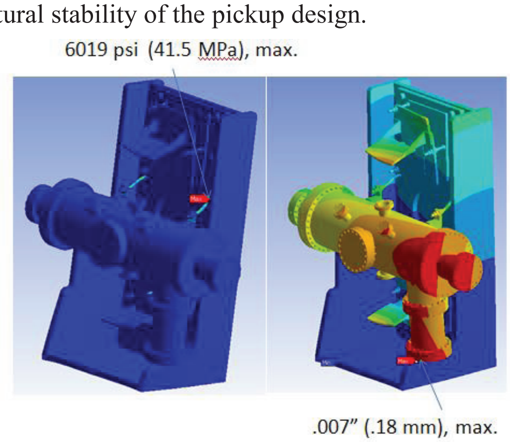

Figure 5: Structural analysis results using ANSYS.

CONCLUSIONS

We have developed a new mechanical design for the transverse stochastic cooling pickup, which can monitor and align the two 4-8 GHz bandwidth bunched beam Stochastic Cooling Arrays precisely without using any wearable mechanical guiding shafts or fragile electronics inside the vacuum chamber. The success of the custom designed image current transition piece, signal feedthrough, and cable strain relief has also improved the reliability of the vacuum components during operation. The pickup has been successfully operated since the 2011 run. The mechanical design has been proven to be robust.

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