Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

THE DESIGN, CONSTRUCTION AND PERFORMANCE OF THE 53 MHZ RF CAVITIES FOR THE NSLS X-RAY RING

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Abstract

Four single cell rf cavities currently provide the required energy to the x-ray ring beam. Mechanical deficiencies and limitations of these early cavities necessitated their replacement with newly designed units. The selection of forged OFHC copper, replacement of traditional Conflat flanges with integrally machined Marmon type flanges, use of commercial spring loaded metal seals for both vacuum and rf purposes and an enhanced thermal cooling system are among the new design features. Ancillary components such as the input couplers and HOM antennae have also been redesigned utilizing a thermally conductivity ceramic material. The design characteristics and performance will be reviewed.

1 INTRODUCTION

The National Synchrotron Light Source (NSLS) consisting of a linac, three transfer lines, a booster and two storage rings (uv and x-ray), has been in operation since early 1980. A total of four 52.887 MHz rf cavities currently provide rf power to the x-ray ring, which operates at current limits of 350mA at 2.584GeV or 254mA at 2.8GeV. The NSLS has upgraded all components to withstand the thermal load associated with increased operating currents of 500mA at 2.5GeV, 438mA at 2.584GeV or 318mA at 2.8GeV. The additional rf power required would increase I^2R losses beyond the design limits of the existing cavities. The original cavity bodies were constructed of copper clad steel. The choice of this material has presented considerable heat transfer difficulties since the water cooling tubes were attached to the external steel surfaces resulting in inefficient thermal conduction. Other significant problems were poor internal surface quality, existence of water to vacuum joints and difficulties in tuning. These difficulties along with new operating conditions have necessitated replacement of these cavities with a new design.

2 NEW DESIGN

A basic goal of the new design was to have a uniform material throughout the rf cavity. Other requirements such as increased reliability by eliminating water to vacuum joints, better temperature control, an easier tuning mechanism, elimination of stainless steel Conflat flanges and considerably fewer external welds and braze joints, have also been implemented. The relatively large physical size, about one meter in diameter by 0.8 meter long, created an engineering challenge to accommodate all these goals.

The design concept was centered on minimizing the number of subassemblies. To accomplish this, the entire cavity was designed mainly from four forged pieces, Fig. 1.

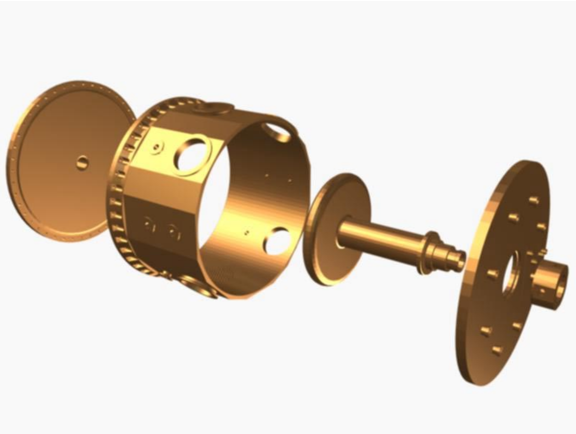

Fig. 1. RF Cavity, Basic Design Concept

The cylinder section, which contains most of the peripheral port flanges, was forged to achieve adequate hardness at the integrally machined port sealing surfaces. The use of conventional Conflat flanges were ruled out due to both incompatibility with rf and the difficulties in joining them to the base copper material. A combination of Marmon type flanges integrally machined into the main forging and a stock seal/clamp mechanism from the Helicoflex company, was proven acceptable. This flange/seal design requires a sealing surface with a minimum hardness of 30 - Rockwell "B". The measured hardness after forging was >40 RB. Electron Beam Welding (EBW) was used as the only joining technique in order to preserve the hardness and prevent grain enlargement. The thermal loads extracted from the SUPERFISH computer program were used to optimize the cooling channel configuration on the structure. Finite element analyses were carried out on the cooling channels to determine the temperature rise and the thermal/pressure deformations. A water flow velocity of 8 Ft/sec yields a film coefficient of 4 Watts/ in^2-°C. An annealed, copper-jacketed seal of approximately 1 meter diameter x 8 mm cross section, furnishes rf contact as well as a vacuum seal for the front cover. This has a sufficient seal deflection range for initial frequency tuning, Fig.2

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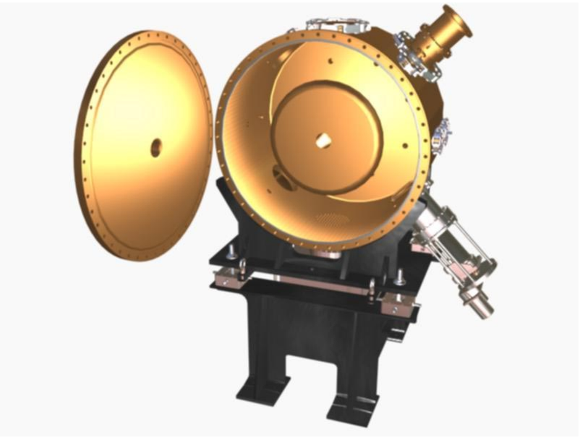

Fig. 2. 52.887 MHz RF Cavity Assembly

To accommodate higher RF power transfer to the cavity and beam, a new, water-cooled, 6" coaxial power input loop/vacuum window was designed, built, tested and installed into the new cavity. Two windows were built, one using an aluminum oxide (Al_2O_3) ceramic, the other, a beryllium oxide (BeO) ceramic. The window body is OF copper and is directly brazed to the ceramic. The loop itself is made from a copper bar in which the cooling channels were gun-drilled to meet within the copper so that no water to vacuum joint exists. In this way the cooling water is very effective in cooling the center conductor. This is brazed to the loop close to the ceramic, insuring minimum heating. The ceramic itself coated with approximately 20 Å of titanium nitride for charge leakage and to reduce multipactoring, Fig. 3.

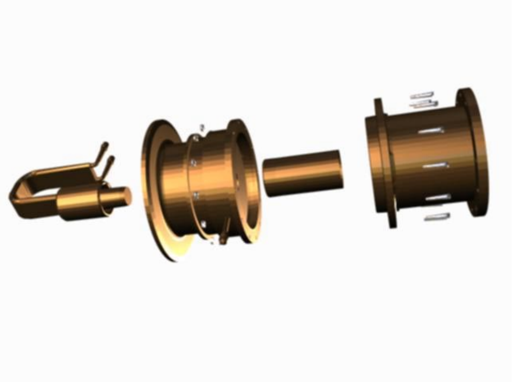

Fig. 3.Coaxial Power Window, Basic Design Concept.

Using the copper cavity with both loops installed, one as the input loop, 3x over-coupled, the other as a 50Ω loaded output loop, 2x over-coupled, rf power at 150 kW-cw was passed through the windows for 10 hours with no noticeable heating or arcing. The Al_2O_3 window has successfully been in operation in the x-ray ring for the past ten months.

3 RF TESTING

After the cavity was received, Q_o was measured at 18000. The input loop was installed, the cavity evacuated to 10^{-9} Torr, and the center electrode heated to 40°C with a closed-loop water system. The center electrode temperature coefficient was measured to be -2.13kHz/°C; the gap sensitivity is 2.2 kHz per mil. Cavity power was then introduced. Several regions of multipactoring were found and recorded. High power was applied to 50 kW within the first eight hours of testing and was increased to 65 kW after several hours for RF conditioning. The overall temperature stability remained within a few tenths of a degree, steady state. The multipactoring regions were conditioned out after 24 hours of operation.

To compensate for reactive beam loading and cooling water temperature variation, a motor driven shorted-loop tuner is used, Fig. 4.

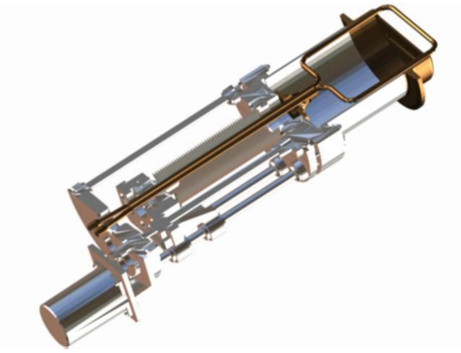

Fig. 4. Shorted Loop Tuner Assembly

By inserting the water-cooled shorted loop into the cavity, the center frequency will be increased. The advantage of shorted loop over plunger tuner is the fact that the high cavity current no longer passes through a sliding contact. However, the small displacement current due to interception of electric field that travels down the loop shaft is returned to the ground through a sliding contact located in the loop assembly.

Seven antennae are inserted into various ports in the cavity for higher order mode damping. Since modes deviate with cavity perturbations, modes were measured throughout the tuner range and the dampers adjusted to insure adequate suppression at all tuner positions. The cavity has been installed into the x-ray ring and successfully operated for the past ten months. Since some of the damping antennae are quite long and intercept many kilowatts of the fundamental field, a high pass filter was designed and installed on them.

Collectively, the damping antennae intercept more than 10 kW of the fundamental field when terminated into 50-ohm loads. To reduce this RF power loss, four of these antennae are fitted with high-pass filters (HPFs) with a cutoff at the first significant higher-order mode (HOM) frequency of 270 MHz, Fig. 5.

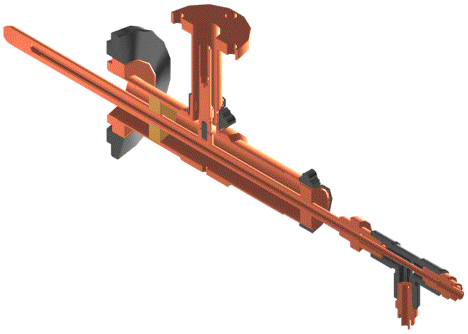

Fig. 5 High Pass Filter Assembly

These HPFs are mounted close to the cavity. One filter is a four-element HPF of the type used on the main cavity of the VUV ring with a fundamental rejection of >60 db. This antenna and HPF is located near the center-electrode E-field region and needs no provision for water cooling of the antenna. Three antennae of significant length are located in the shorting wall of the cavity and are heated by rf currents generated by the large magnetic field present there. These antennae dissipate up to 300 watts and are therefore fitted with three-element HPFs designed to pass cooling water through a shorted stub which also acts as the first inductive element of the filter (see Figure 5). Water is supplied through a spit tube and returns coaxially through the center conductor. A coaxial capacitor and a shunt inductor complete the three-element HPF and carry away the HOM power from a tap on the shorted stub. These HPFs have a fundamental rejection of >40 db. The antennae have been in operation for more than ten months.

4 CONCLUSION

The replacements of NSLS x-ray ring RF cavities are being implemented with newly designed peripherals. ACCEL Instruments in Germany has built the first two RF cavities, Fig. 6.

Fig. 6. 52.887 MHz RF Cavity Assembly

The first unit was tested and installed with newly designed ancillary components. The RF, vacuum and temperature stability and control performance have been well within design goals. The repeatability and reliability of the Marmon type flanges using Helicoflex seals have been found mainly to depend on the seal quality control. The second rf cavity is scheduled to be installed during the NSLS 1999 winter shutdown.

5 ACKNOWLEDGEMENTS

The authors Would like to thank the NSLS support personnel, particularly, R. D'Alsace, R. Freudenberg, N. Guglielmino, J. Newburgh, G. Ramirez, T. Rodrigues, S. Pjerov and J. Vaughan for their excellent technical efforts.

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