MECHANICAL DESIGN OF SXLS RADIO-FREQUENCY CAVITY*

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Abstract

This paper presents the mechanical design of a Radio-Frequency (RF) cavity to be used on a compact storage ring for Superconducting X-ray Lithography Source (SXLS). Various design features of this cavity are discussed, including basic geometrical configuration, structural design, initial and operational tuning, vacuum multipactoring, power window, and damping of higher order modes. A second application of this cavity design for beam life extension in an existing storage ring is also described.

Introduction

Recent progress in X-ray lithography has demonstrated the potential of this technology for industrial production of integrated circuits with sub-micron size devices. A key component to the success of this technology is the development of a cost-efficient, reliable and portable X-ray source. A Superconducting X-ray Lithography Source (SXLS), which would meet these requirements, is currently under design at the Brookhaven National Laboratory (BNL). The proposed SXLS, to be built in two phases, will have a compact storage ring of 8.5 meter circumference. In the first phase a mock-up of the SXLS with a ring energy of 200 MeV will be constructed using conventional dipole magnets. This machine will be used primarily for machine physics and low energy injection studies. Superconducting dipole magnets of 4 tesla field will replace the conventional magnets in the second phase when the beam energy would be increased to 696 MeV. The RF cavity will operate at the same nominal resonance frequency of 211.5 MHz in both Phase I and II machines, but with different gap voltages of 20 Kv and 150 Kv, respectively. The RF cavity for Phase I discussed in the following sections is designed to provide up to 70 kv peak RF voltage.

Basic Geometrical Configuration

Because of the compact size of the SXLS storage ring there are strict space limitations on the overall size of the cavity. A computer program, SUPERFISH, was used to match the available internal cavity space with the resonance frequency of 211.5 MHz. Figure 1 shows the basic geometrical configuration of the cavity that was found acceptable. SUPERFISH was also used to determine the rate of change of resonance frequency with the changing gap size. The predicted rate of 4.32 MHz/mm shows that the resonance frequency is highly sensitive to the gap size variations. Thermal and pressure deformation of the cavity were, therefore, carefully evaluated during the design process.

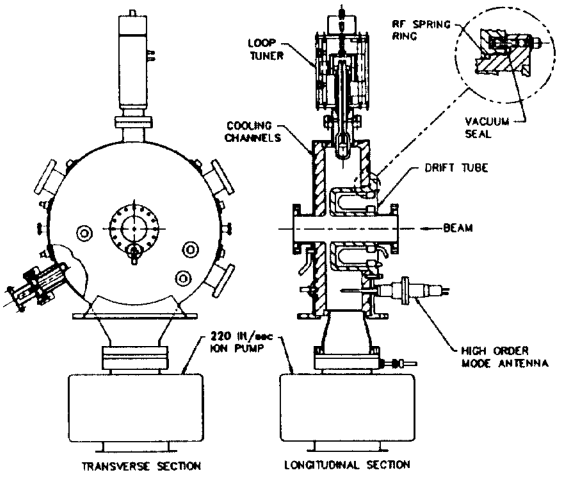

Fig. 1 RF Cavity Assembly

Structural Design

The specified power loss of 10 kw is the governing factor in the present design. Consequently, Oxygen Free High Conductivity copper (OFHC) was selected as the fabrication material because of its high thermal conductivity, excellent mechanical and electrical properties and acceptable outgassing rate. A finite element program, ANSYS, was used to optimize the cooling channel configuration in the cavity. The cooling channels are to be machined onto the outside of the cavity structure (see Fig. 1) and subsequently plated with copper by the electroforming process. Compared to the brazing of copper tubes on the outside surface as is commonly done, this technique has two main advantages: firstly, it enhances heat transfer by providing a direct cooling path to water channels, and secondly, it eliminates the need for brazing which can cause recrystallization of the copper.

An axisymmetric finite element analysis of this cavity design was carried out to determine the temperature rise and thermal and pressure deformations. Heat load distribution on the internal cavity surface was computed by the SUPEFISH program. A water flow rate of 5 GPM was used which yielded a convective film coefficient of 1 watt/cm^2. Constant temperature contours for the maximum heat load of 10 kw are depicted in Fig. 2.

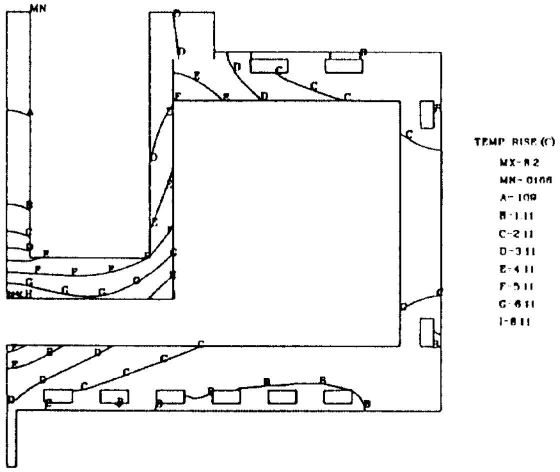

Fig. 2 Temperature Contours in the RF Cavity

As shown in the figure, the temperature rises by 2 -3°C in the main cavity body and by 5 - 6°C in the drift tube. The resulting thermal deformation would increase the gap size by up to 0.03 mm

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depending on the RF power dissipation. This corresponds to a frequency change of up to 130 kHz which must be compensated by operational tuning device.

Analysis results also show a decrease of 0.08 mm in the gap size under vacuum pressure forces. However, since this decrease in gap size remains constant once the vacuum has been established, it can be readily compensated during the initial tuning.

Initial and Operational Tuning

Initial tuning is carried out by properly locating the drift tube relative to the previously welded cover plate. Two seals are employed for the necessary attachment as shown in Fig. 1. The first seal, made of silver coated copper coil, is located between the inner surfaces for RF contacts, whereas the second seal, commercially known as HELICOFLEX, is placed near the mounting bolts to serve primarily as a vacuum seal. Through a sequence of step maching of the drift tube nose, the correct gap size can be obtained. This machining sequence will take into account the effect of the structural deflections due to vacuum forces as well as due to thermal cycling during bake out.

Operational tuning will be performed by a motor driven loop that is shorted at one end, Fig. 3 and mounted at a radial location where the magnetic field is strongest. The loop will be automatically adjusted inside the cavity to compensate for the reactive beam loading and mechanical tolerances. This tuner will provide a maximum frequency adjustment of ± 250 KHz which is substantially higher than that required for compensating the thermal deformations (130 KHz).

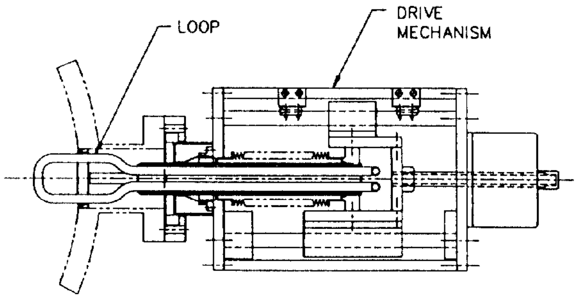


Fig. 3 Motor Driven Operational Tuner

Vacuum

A conical-shape vacuum port, Fig.1, has been designed to facilitate high speed pumping of the cavity by a 220 lit/sec ion pump. The number of air to vacuum joints is kept to a minimum in order to increase the vacuum integrity while decreasing the fabrication cost. Strict cleaning procedures are specified to assure successful joints and to minimize outgassing during operation. After assembly and vacuum leak check, the cavity will be baked with electric heating jackets to 150°C for 24 hours. Following the bakeout, the unit will be conditioned at various RF power levels up to a maximum of 10 kw.

Multipactoring

Problems associated with multipactoring in regions of high electric field gradients are well documented. In RF cavities the potential for multipactoring due to stray electrons from field emission is relatively high. These energetic electrons can, upton impact on the RF surfaces, produce X-rays, which in turn can create photoelectrons. This process not only results in a higher vacuum pressure, but also leads to the deterioration of the surfaces. Other deleterious effects include absorption of the RF power, beam instability and lower beam lifetime.

The secondary electron emission coefficient (SEEC) of the RF surfaces must be brought down to below unity, in order to minimize the multipactoring effects. This can be accomplished by coating the RF surfaces with a thin film (about 100 Angstroms) of titanium and/or titanium nitride [1]. The adopted procedure, which has been successfully tested on an existing all copper cavity, consists of evaporating a commercially available titanium ball for 3-5 minutes at a pressure lower than 10^{-6} torr. The cavity is then backfilled with dry nitrogen which leads to a partial conversion of the titanium film into titanium nitride. Oxidization of the remaining titanium film, which can increase the SEEC to greater than unity is suppressed by re-conditioning the cavity after each exposure to the air. This coating method is much simpler than a commercial procedure that requires high surface temperature of up to 500 °C. In the latter procedure, a titanium film is first deposited by evaporating titanium filaments located near the surfaces. The cavity is then heated in a vacuum furnace in the presence of ammonia which reacts with the titanium at high temperature to form titanium nitride.

Power window

Power is fed into the cavity via a 50 ohms coupling loop using a coaxial feedthrough as a barrier (Fig. 4). This commercial off-the- shelf feedthrough is made of high-strength, high-alumina (Al203) ceramic. Total power loss in the ceramic is calculated to be.24 watts which can be dissipated to air by natural convection. Vacuum-side surface of the power window will be sputtered with titanium if it shows any of the effects of multipactoring.

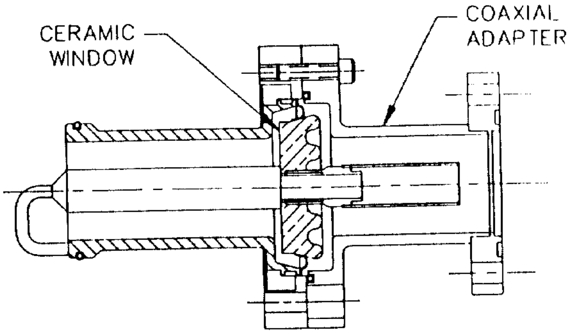
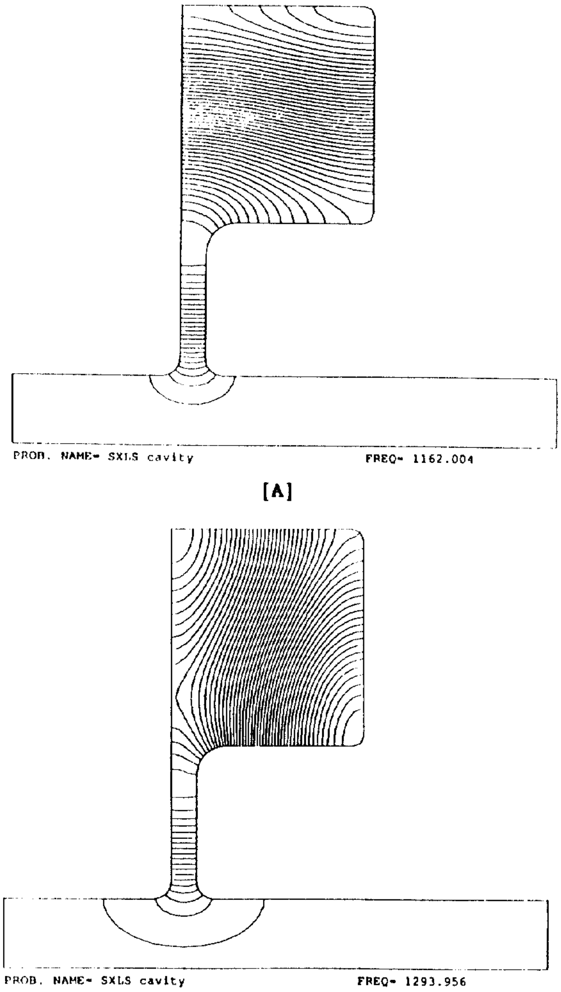


Fig. 4 Power Window

Higher Order Mode Suppressors

The program SUPERFISH predicted two higher resonance frequency modes of 1162 MHz and 1294 MHz, Fig. 5A and 5B. To damp these modes without perturbingthe H field and Q of the fundamental mode, a thin coaxial water-cooled electric field probe (called antenna) is designed, Fig. 6. Appropriate ports are provided on the cavity body for two antennas as shown in Fig. 1.

A water-cooled resistor load, made by BIRD Electric Corporation, is used to absorb the RF power by converting it to heat in the resistor.



[A]

[B]

Fig. 5 Higher Order Resonance Frequency Modes

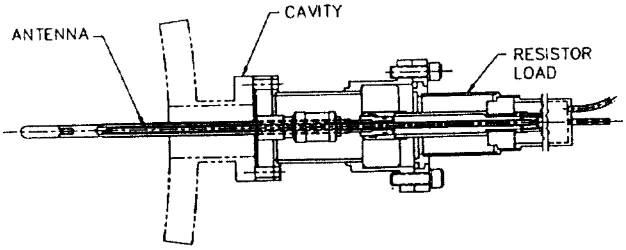


Fig. 6 Antenna for Suppressing Higher Order Modes

Use for Beam Life Extension

Beam life in the VUV storage ring at the National Synchrotron Light Source is adversely affected by the high density of the electron bunches. An additional Rf cavity, identical to the SXLS cavity described above, will be installed on this ring in order to decrease the bunch density. The cavity, referred to as the fourth harmonic cavity because its resonance frequency is the fourth harmonic of the fundamental frequency, would create a flat region in the acceleration field waveform, thereby increasing the bunch length [2]. The present design has been adopted for this cavity because a previous design, in which the cavity was made of stainless steel both with and without copper plating, resulted in a runaway frequency condition primarily due to the poor heat transfer.

Conclusions

Mechanical design of an all copper RF cavity for the Superconducting X-ray Lithography Source has been described. The design has been optimized for space and functional requirement by analytical studies using SUPERFISH and ANSYS computer programs. Resonance frequency variation due to thermal deformations are minimized by water channels machined onto the main structure. The effects of pressure deformations, residual thermal deflections and mechanical tolerances are compensated by adjusting the gap size through step machining of the drift tube nose which is separable from the main body. Ultra high vacuum is achieved by pumping through a conical-shape vacuum port with a 220 lit/sec ion pump. The design provides for a tuner to compensate for the frequency drift under thermal and reactive beam loads during the operation, and antennas for the suppression of higher order modes. Multipactoring effects are controlled by sputtering the cavity with titanium and backfilling it with dry nitrogen.

References

[1] E. W. Hoyt and W. P. Schulz, Titanium Nitride Coating of Aluminum Multipactoring Accelerating Structures, Stanford Linear Accelerator Center, SLAC-TN-75-3.

[2] J. M. Wachtel, On Bunch Lengthening Using the Fourth Harmonic Cavity in the NSLS VUV Ring, Brookhaven National Laboratory, BNL-40929.