SXLS RF Cavity and System*

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Abstract

The design of a 700 MeV superconducting compact electron storage ring for applied X-Ray lithography is in its final stage. This succeeds a 200 MeV warm dipole model constructed and now in operation at BNL. RF cavities and systems in both machines will be discussed. This paper will present cavity design parameters, construction, and the kind of mode suppression as well as the type of tuner and input window to provide 300 KV of accelerating voltage at 211.54 MHz. A 65KW, RF power source will be described.

I. INTRODUCTION

Recent interest in synchrotron radiation as a source of X-rays for lithography from large electron storage rings has stimulated the design of rings of a more compact size. The 51 meter circumference VUV ring, and the 170 meter X-ray ring at the National Synchrotron Light Source (NSLS), are two examples of the larger storage rings. These are machines emitting radiation from conventional magnets based on well established engineering technology.

The design and construction of an 8.5 meter circumference Superconducting X-Ray Lithography Source (SXLS) at the NSLS at Brookhaven was funded by DARPA in 1988, in which machine building technology will be transferred to two companies in U.S. industry, the Grumman Aerospace Corp. and General Dynamics.

Phase I of the project, a 200 MeV, conventional magnet machine was completed in the fall of 1990 and has been in operation since then for low energy injection studies and machine diagnostics. A low level, 10KW RF cavity[1] and system are used that will be upgraded to a 65KW system for the Phase II, 700 MeV, superconducting machine. The Phase II cavity is designed and will be described below. Some construction details and operation of the Phase I cavity and system will also be discussed.

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Phase II Cavity Structural Design

The overall space available, both axially and radially, has remained unchanged compared with the Phase I cavity, but with the higher input power required, the cavity had to be designed in such a way to have sufficient surface cooling for manageable heat removal and still maintain adequate capacitance across the gap. The final design, shown in Fig. 1, consists of three main sections joined together with two circumferential electron beam welds. The number of mechanical joints was kept to a minimum in order not to compromise the vacuum integrity and Q of the cavity.

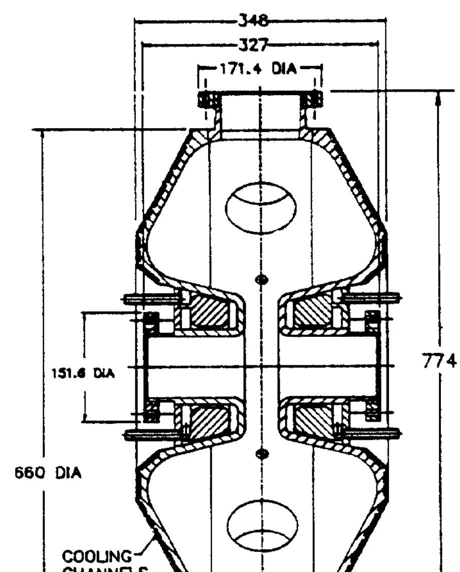

Fig. 1

For a maximum of 300 KV gap voltage, the total dissipated power was calculated to be 27.5 KW which is distributed on the inside surfaces of the cavity. For adequate cooling and maintaining high Q, Oxygen Free High Conductivity (OFHC) copper was selected as the base material. A series of rectangular grooves are machined over 75% of the external surfaces, and subsequently copper plated into channels by an electroforming process.

The finite element program, ANSYS, was used to optimize the cooling channel configuration on the structure. An axisymetric finite element analysis was carried out to determine the temperature rise and the thermal plus pressure deformation. A water flow rate of 20 GPM is distributed through several parallel channels to maintain water velocity of 10 Ft/sec, which yielded a convective film coefficient of 1.4 Watts/Cm^2°C. A maximum heat load of 27.5 KW results in a temperature gradient causing a deformation, mainly across the drift tube, by 0.16 mm. This inward displacement reduces the final resonant frequency by 200 KHz which is adjusted for in the fabrication. The complete cavity assembly with peripheral equipment installed is shown in Fig. 2.

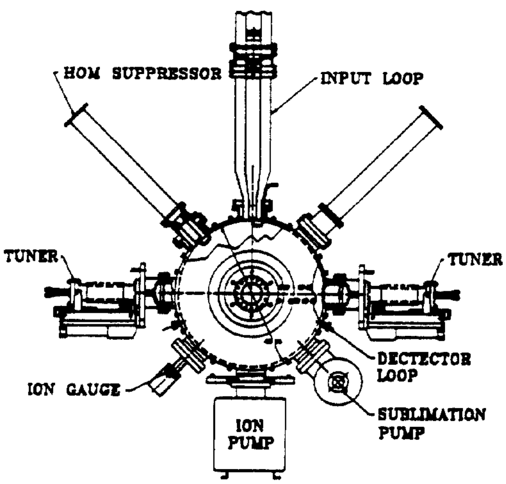

Fig. 2

A commercial heat/cool refrigerating pumping system, capable of maintaining a set temperature to within ±1°C, provides the necessary flow rate during operation.

The vacuum window for the drive loop, due to power restrictions, will be a standard 6 inch coax type used in other cavities at the NSLS. Since the port openings in the cavity are smaller, a half-wavelength tapered section will be installed between the cavity and the window.

A ferrite frequency tuner has been ordered to use in the resonator to compensate for reactive detuning. A 53 MHz tuner of similar design is currently being tested at this facility.

Multipactoring and RF Conditioning

After cleaning, assembly, and vacuum leak checking, the XLS Phase I Cavity was baked for 48 hours at 150° C and upon cooling, RF power was applied to condition the inner surfaces.

The XLS cavity had multipactoring levels in regions of 1W, 15W, 600W, 1200W, 1700W, 2400W, 6000W and 9000W that were difficult to condition out. It was decided to coat the cavity with titanium nitride using a method developed at SLAC[2] and successfully used in other cavities at the NSLS.

Varian 'Ti-Balls' were placed into the cavity in various positions to uniformly distribute a 100-200 angstrom coating of titanium/titanium nitride upon the inner surfaces. The vessel was evacuated to 10^{-7} Torr and dry Nitrogen gas leaked in to a pressure of 2-4x10^{-5} T. The Ti-Balls are heated for a specific time followed by a 2 hour nitrogen soak for more nitride conversion, before removal.

After this process, the cavity was RF conditioned and only the 1W multipactoring level remained. It should be noted that the vessel was cycled several times to dry nitrogen and to air, and after evacuation each time, the surfaces remained conditioned. The SXLS Phase Two Cavity will be prepared in the same fashion.

Higher Order Mode Suppression

Phase I cavity high order modes were damped using four damping antennae and two shorted loops. The damping antennae couple power out to 50 ohm water cooled loads. The cavity is a quarter wave T.E.M. resonator, capacitively loaded with a removable drift tube.

Mode damping was accomplished by first measuring the cavity spectra as a reference. Field plots from both URMEL and SUPERFISH were studied for high E field patterns of the undesirable modes. Model probes loaded with 50 ohm terminators were placed in available ports to penetrate regions

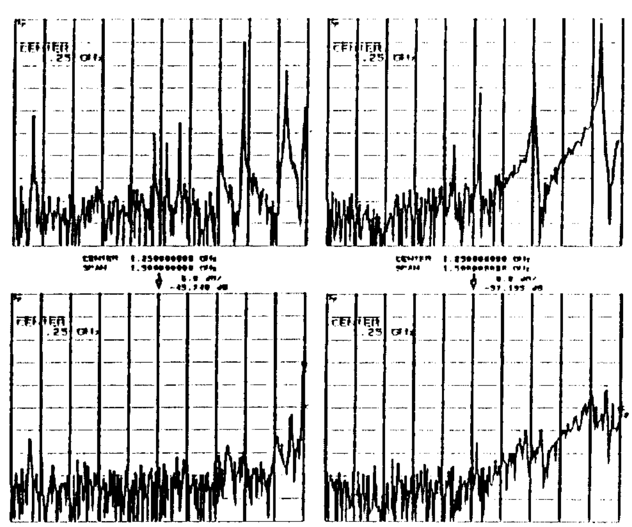

Fig. 3

of high field density. The length of each probe was adjusted for maximum mode attenuation. Care was taken to avoid coupling to the fundamental. A dipole mode at 600Mhz was damped with two shorted loops installed at ports located 90° apart. The adjustable shorts were positioned for maximum damping and then locked into place. The results of damping the dipole and monopole modes are shown in Fig. 3.

For the Phase II Cavity, a broadband mode damper was developed using a wave guide as a high pass filter. The waveguide design chosen is a capacitively "T" loaded wave guide which reduces the waveguide dimensions to be compatible with the cavity port dimensions. The cutoff frequency of 300 MHz presents good isolation of the fundamental and a reasonable guide wavelength for an overall broadband termination. Fig. 4a shows the SUPERFISH field plot of the waveguide at cutoff.

Several terminations were tried on the waveguide: simple resistors in parallel across the gap, and two different taper lengths of ferrite loaded rubber. A 'discrete' slotted line was developed by drilling probe holes along the length of the waveguide and measuring the standing wave. The 8 inch taper was chosen (see Fig. 4c) as a result of these measurements. It is believed that the increase in VSWR at 2518 MHz is a result of a higher order mode propagating in the waveguide, with a cutoff frequency of 2426 MHz, which is not properly terminated. The final design will include absorber material placed to attenuate this mode.

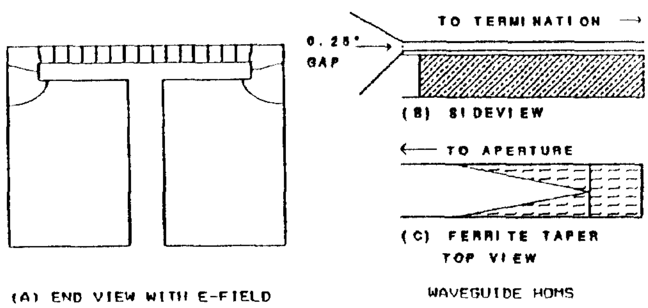

Fig. 4

The coupling was arrived at empirically, by optimizing the attenuation of monopole modes with a single waveguide. Aperture coupling was the most successful and was optimized by extending the top and bottom surfaces of the waveguide gap into the cavity then tapering them to intercept more field, much like a parallel plate tapered horn, as shown in Fig. 4b.

Two aperture coupled waveguides were installed orthogonally to each other and tested on a low power test cavity. The results are shown in Table I. In the final design, the rubber-based ferrite absorber will be replaced with a vacuum compatible ferrite material.

RF System and Control

A single 65 KW, 211.54 MHz RF power amplifier system is required to supply power to the cavity field gradient and for beam loading. The system will have amplitude and phase control as well as 1 MHz of resonator tuning to compensate for the reactive loading of 0.5 amps of beam current.

All setpoints and monitors will be computer controlled through a CAMAC interface chassis driven by HP workstations[3]. Two custom boards will contain the phase, amplitude and tuner controllers.

MONOPOLES		DIPOLES	
FREQUENCY (MHz)	Attenuation (dB)	FREQUENCY (MHz)	Attenuation (dB)
214	0.18	620	7.5
785	17	855	5
1044	17	1144	16
1452	13	1575	12.5
•1494•	10.5	1917	0
1757	12.5	1369	11
2022	12.5	•1494•	6.5
		1875	12.5 - 15
2256	7 to 11	2118	17.5
2501	.5	2315	8.5 - 11
2594	1.5	2452	5
2833	.5		
2959	6		

Both waveguides were terminated with an 8 inch ferrite taper and aperture coupled using "duckbill" extensions of approximately 2.5 X 3.5 inches. The flange extension was angled at 30 to 45 degrees, T-ext at 45 degrees.

Table I

A 4KW, solid-state amplifier drives power into the final stage powered by a water-cooled Eimac 4CW100,000E tetrode, fitted into a custom resonator. The complete system is being manufactured by the QEI Corporation, Williamstown, N.J. as per NSLS specifications.

Conclusions

The Phase I facility has operated with circulating beam in excess of 1 ampere at 200 MeV, and consistently runs with currents of 600 mA. Injection studies are also being done at 80 MeV and at 120 MeV. The Phase II cavity and RF power assembly should be ready for assembly and test in about one year.

Acknowledgements

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