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1500 MHZ Passive SRF Cavity for Bunch Lengthening in the NSLS-II Storage Ring

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DISCLAIMER

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Abstract

NSLS-II is a new ultra-bright 3 GeV 3rd generation synchrotron radiation light source. The performance goals require operation with a beam current of 500mA and a bunch current of at least 0.5mA. Ion clearing gaps are required to suppress ion effects on the beam. The natural bunch length of 3mm is planned to be lengthened by means of a third harmonic cavity in order to increase the Touschek limited lifetime. After an extensive investigation of different cavity geometries, a passive, superconducting two-cell cavity has been selected for prototyping. The cavity is HOM damped with ferrite absorbers on the beam pipes. The two-cell cavity simplifies the tuner design, compared to having two independent cells. Tradeoffs between the damping of the higher order modes, thermal isolation associated with the large beam tubes, and overall cavity length are described. A copper prototype has been constructed, and measurements of fundamental and higher order modes will be compared to calculated values.

INTRODUCTION

The NSLS-II storage ring RF system will have four 500MHz superconducting single-cell cavities providing 4.9MV total ring voltage. Without the harmonic cavity the bunch length is ~3mm rms and the resulting lifetime is ~2 hours, which would require frequent top-off injections that would interfere with user operations. An established method [1, 2] of increasing the lifetime is to use a harmonic cavity to flatten the potential well and lengthen the bunches; this decreases the charge density and increases the lifetime for Touschek lifetime-limited machines. Performance is limited due to the ion-clearing gap transients, which induce a phase offset of the bunches along the bunch train, limiting the beam-induced voltage. Passive super-conducting RF cavities [3, 4] can decrease this effect by a factor of ~2 by being able to reduce the R/Q, which is not practical in normal conducting cavities. To reach the flattened well distortion with a third harmonic system, two passive 1500MHz superconducting RF two-cell cavities are used to generate ~1/3 the fundamental voltage (=1.6MV).

Table 1: NSLS-II Parameters

Beam energy	3 GeV
RF frequency	500 MHz
Average Current	500 mA
Circumference	792 m
Harmonic number	1320
# cavities(500MHz single-cell)	4
# cavities(1500MHz two-cell)	2
Cryogenic temperature	4.5 K

1500 MHZ CAVITY FOR NSLS-II

Several options for the harmonic cavities for bunch lengthening were studied; normal conducting passive and active cavities, and superconducting passive cavities. The decision to use SRF passive cavities is based on the lower R/Q that can be achieved with their design, which limits the transient induced by the ion clearing gap [5]. The approach to the design of the NSLS-II harmonic cavity was influenced by the restrictions imposed by the available RF straight lengths, and the new requirements for compliance with ASME pressure vessel codes. It was decided to pursue a coupled two-cell cavity approach (Fig. 1) that saves space and allows a single tuner mechanism outside of the cryostat, and utilizing beam-pipe HOM dampers that avoid penetrations into the niobium structure.

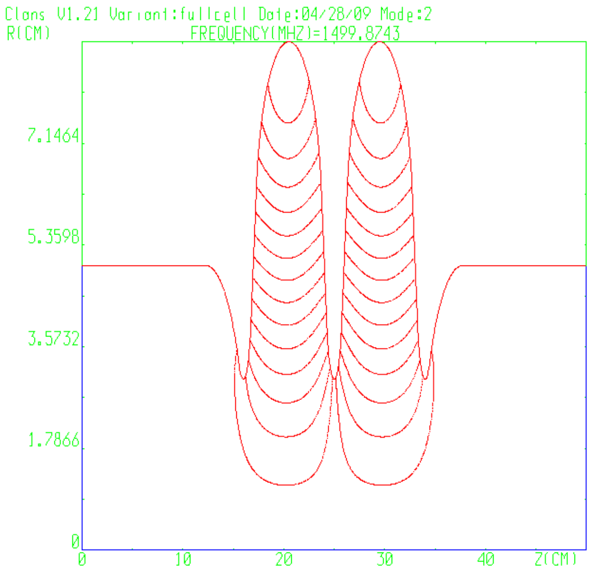

Figure 1. CLANS plot of π mode.

Table 2: NSLS-II Harmonic Cavity Parameters

Freq(π-mode)	MHz	1500.07
E_zeroT	MV/m	5
L	m	0.2
V (per cell)	MV	0.50

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Eo	MV/m	7.412
Ep	MV/m	12.784
Bp	mT	22.063
T	K	4.5
Rres	Ohm	1.0E-08
Pd	W	9.4
U	J	0.237
Q	--	2.4 x 10^8
R/Q	Ω	112
TTF	--	0.675
Freq(0-mode)	MHz	1481.06
R/Q (0-mode)	Ω	3.3

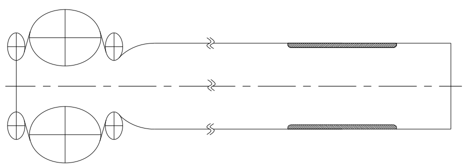

Figure 2: Geometry of NSLS-II 3rd harmonic cavity. Left side is symmetry plane.

CALCULATION OF HOMS

The 2D codes CLANS and CLANS2 were used to calculate the longitudinal and transverse HOMs. Calculation results of HOM damping are shown in Tables 3 and 4.

Table 3: Longitudinal HOM Impedances

Frequency (MHz)	Q	R (Ω)
2310	1589	1.36E+02
2356	408	2.65E+02
2432	191	5.76E+01
2535	113	2.54E+02
2663	75	8.24E+01
2896	617	2.45E+03
2948	205	3.12E+03
2992	47	2.20E+02
3126	205	9.03E+01
3208	231	4.73E+01
3335	49	1.93E+02

Table 4: Transverse HOM Impedances

Frequency (MHz)	Q	R (transv.) (Ω/m)
2066	87	2.17E+04
2206	1640	3.25E+04
3669	213	2.77E+03
1980	172	4.78E+04
2085	73	3.34E+04
3058	75	1.20E+04
3935	1361	2.10E+02

HEAT LOSS CALCULATION

A 1500MHz SCRF cavity is surrounded by the liquid helium vessel, in turn surrounded by the heat shield and vacuum vessel. Since the cavity is passive and does not require a power coupler, the heat leak is dominated by the large beam tubes required to couple the HOMs to the ferrite load. The niobium cavity is connected to the ferrite load via a thin stainless steel tube with copper plating. In order to reduce the length required, the transition is anchored at 77 K with a LN2 heat sink.

The heat loss is calculated including the thermal conduction from 4.5 K to 77 K, 77 K to 300 K, and RF surface loss of fundamental mode at 4.5 K and 77 K. We fixed the heat leak to 4.5 K at 3 watts per transition, fixed the thickness of the SS and Cu, and calculated the distribution of beam tube temperatures. The length of the transitions required to meet these conditions was then determined. Although we have a self-consistent design with the 3-watt heat loss to 4.5K, if we decide to increase the beam-pipe diameter we will let the heat loss increase, as we are at the limit of the cavity length. Likewise the cavity length could be shortened at the expense of cryogenic losses, which are low in the current design.

Calculation parameters are shown in Table 5, and the result is shown in Fig. 3.

Table 5: Static Heat Leak of NSLS-II 1500MHz Cavity

Frequency	1500 MHz
Heat leak to LHe from LN_2 (one side)	3 W
Heat leak to LN_2 from 300K (one side)	17 W
LHe temperature	4.5 K
Inner radius of stainless beam tube	50 mm
Thickness of copper plating	10 μm
Thickness of stainless tube	2.5 mm
Start point of stainless tube from center	20.0 cm

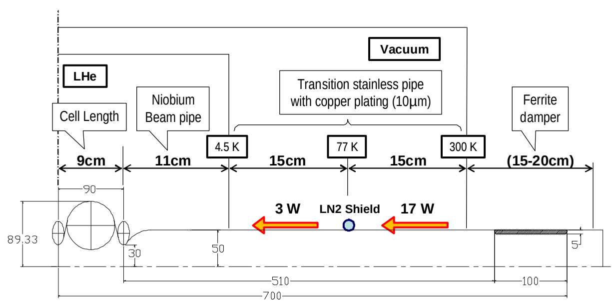

Figure 3: Cryomodule design of 1500MHz cavity.

OPERATIONAL ISSUES

In order to "park" the passive cavity to reduce the induced voltage during short bunch operations, or in the event the cavity has a problem, it must be able to be detuned far from the RF harmonic line, as shown in Figure 4. A 1MHz tuning range is specified, which will reduce the cavity voltage to 84 kV when parked, where the induced voltage will have a negligible effect on the bunch shape.

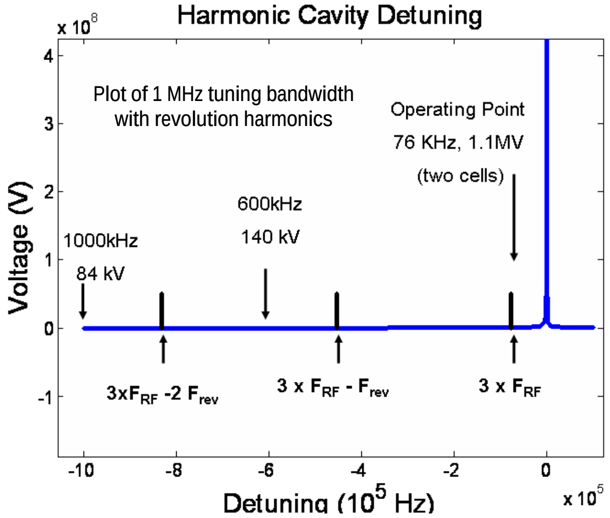

Figure 4. Induced pi-mode voltage as a function of cavity tuning.

A disadvantage of the two-cell design is the trapped zero-mode in the cavity. This mode must be prevented from approaching a beam revolution line, which would dump the beam and possibly damage the cavity. The frequency separation between the zero and pi mode is determined by the coupling between cells,

$$\omega_m^2 = \omega_0^2 \left\{ 1 + 2k \left(1 - \cos\left(\frac{m\pi}{N} \right) \right) \right\},$$

where k is the coupling constant, m is the m[th] mode, and N the number of coupled cavities. For the cavity geometries studied, k ~1.2% and the mode separation is ~18 MHz. Since the mode separation is a function of the coupling constant only, the 0-mode should track the pi mode and avoid dangerous revolution lines. Fig. 5 shows the zero-mode excitation for an R/Q of 3.3 as a function of frequency offset from the 3rd harmonic of the RF. An earlier cavity geometry achieved a 0-mode R/Q of 0.03, which will further reduce the induced voltage, limited by the field flatness achieved during cell-to-cell tuning.

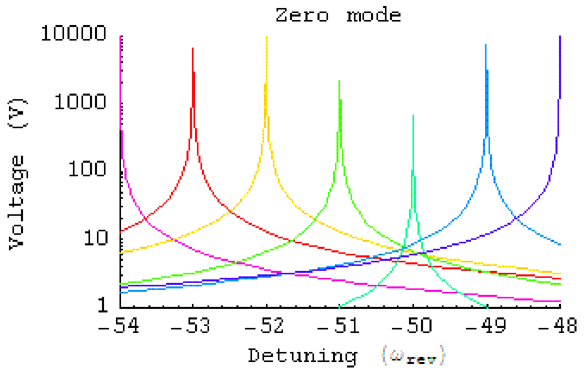

Figure 5: Zero-mode excitation spectra with 1MHz detuning. The X-axis is the distance in revolution lines from the third harmonic of the RF frequency.

1500MHZ CAVITY DESIGN AND COPPER MODEL

According to calculation of HOMs and thermal loss, we designed a prototype 1500MHz cavity. A copper prototype has been fabricated [Fig. 6] to measure the higher order mode damping, cell-to-cell coupling, and the tracking of π- and 0-mode frequencies during tuning.

Figure 6: Copper prototype undergoing bead perturbation field measurements.

SUMMARY

A cavity design has been developed for a passive SRF 3[rd] harmonic cavity consisting of two tightly-coupled cells. The preliminary design has resulted in a compact, low-loss structure with highly damped HOM impedances. Studies are ongoing to confirm the feasibility of operating a two-cell structure in a high-current storage ring, and in methods of damping the 0-mode, if necessary.

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