DESIGN OF A 1500 MHZ BUNCH LENGTHENING CAVITY FOR NSLS-II

J. Rose*, N. Towne, Brookhaven National Laboratory (BNL), USA
T. L. Grimm, C. H. Boulware, Niowave, Inc., USA

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. A niobium cavity and full cryomodule including LN2 shield, magnetic shield and insulating vacuum vessel have been fabricated and cold tested. The cavity design and initial cold test results are presented.

INTRODUCTION

NSLS-II storage ring RF system will have four 500MHz superconducting single-cell cavities providing 4.9 MV 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 will 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 bunches which decreases the charge density and increases the lifetime for Touschek lifetime limited machines. The design and test of a 2 cell 1500 MHz cavity for bunch lengthening is presented.

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 RF DESIGN

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 in electron storage rings [3]. An innovative approach with two coupled cells in a common cryostat was taken that allows very strong damping of HOM's and a room temperature external tuner in a relatively compact space. However, having the two coupled cells results in two fundamental modes, 0 and π. The unwanted 0-mode cannot be damped since the frequency separation between the zero and the pi mode is only 21 MHz, too close to easily filter. Since the mode spacing is fixed by the coupling we realized that careful control of the 0-mode in design and in operation would keep the 0-mode fields to acceptable levels. The excitation of the 0-mode is much less sensitive than the π-mode due to a couple of large factors that work in our favor. First is the careful design of the cavity geometry for minimum impedance of the 0-mode by adjusting the length of the two cells to get a near perfect cancelation of the 0-mode fields due to the transit time factor of the cavity. Second, the intensity of of the revolution lines in the vicinity of the zero mode are a factor of 30 less than near the 3rd harmonic RF line.

The design goal of the 1500 MHz harmonic cavity was to achieve an R/Q of the π-mode of < 90 ohms [3], an R/Q of the 0-mode of << 1 ohm and a large beam pipe diameter to reduce the wake field heating of the ferrite mode dampers to acceptable levels. These goals were achieved (Table 2) by taking the conceptual cavity design [4] and increasing the beam pipe diameter to 120 mm, increasing the iris between the cavities to 38 mm and iterating the cell lengths to reduce the 0-mode impedance. The cavity geometry is shown in Figure 1.

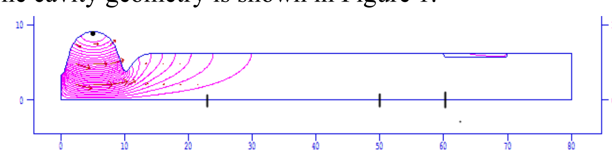

Figure 1: 1500 MHz cavity geometry with Nb-Cu interface (4K), 77K shield and 300K interface marked on axis.

Table 2: NSLS-II harmonic cavity parameters.

Freq(π-mode)	MHz	1499.25
R/Q (Pi)	Ω	88
Q_0	@4.5K	$2.6*10^8$
Accelerating Voltage	MV	1.0
Freq (0-mode)	MHz	1478.03
R/Q (zero)	Ω	0.15
Q_0	@4.5K	$2.7*10^8$

The cavity thermal design trade off was made by keeping the thermal heat leak to 4.5 K and the dynamic RF losses to the Cu plated stainless steel thermal transition to less than 10% of the superconducting RF dynamic losses. A thermal heat shield was incorporated at 50cm from the cavity center point. Figure 2 shows the power dissipated per segment as calculated by Superfish. Segments 1cm long starting at the Nb-Cu interface in the straight beampipe shows the power losses of the fundamental evanescent mode as it decays. The boundary between Nb and Cu is clearly seen at the end of segment

---
*rose@bnl.gov

18 (24cm) where the losses increase in the normal conducting Cu. The available space in the NSLS-II RF straight for the harmonic cavity was 1.5 meters. Leaving 300mm for the HOM dampers the cavity length flange to flange inside the HOM dampers is 1.2m. The niobium beam pipe extends to 24 cm from center; this also defines the 4.5K boundary. By setting the 77k anchor point at 50 cm from cavity center the calculated thermal heat leaks from 300K to 77K Watts and 77K to 4.5K are 21 and 2.2 Watts respectively. This is a reasonable balance with the LHe heat leak < 10% of the dynamic RF losses.

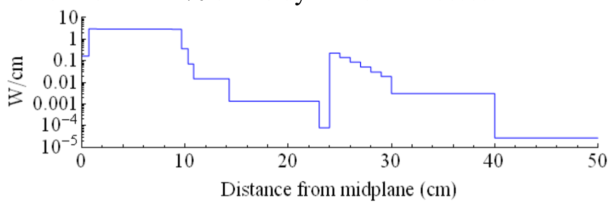

Figure 2: Power dissipation at along cavity and thermal transition boundary.

CALCULATION OF HOMS

The complete cavity string design includes 2 ferrite beam pipe HOM dampers is shown in Figure 3.

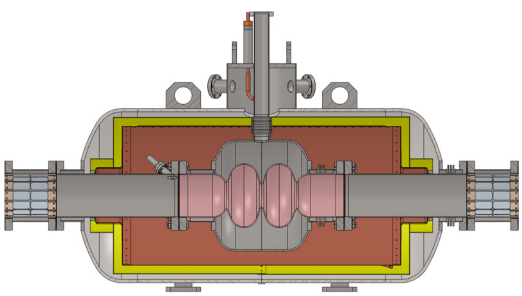

Figure 3: Geometry of NSLS-II 3rd harmonic cryomodule.

The 2D codes CLANS and CLANS2 [5] were used to calculate the longitudinal and transverse HOMs. C48 ferrite material from Countis Industries was used in the modelling of the HOM damper performance. The ferrite HOM dampers start 600mm from the cavity mid-plane. Several higher order modes are more lightly coupled to the new ferrite locations. In particular the transverse TM111 mode at 2145MHz (Figure 4) has an impedance of 41kOhm/m.

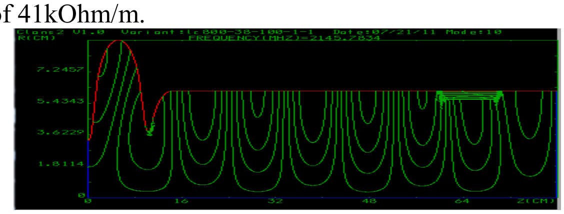

Figure 4: Magnetic field isolines of the highest impedance dipole mode- at 2145MHz.

This is a factor of eight increase from the highest impedance in the previous [4] design. Further studies will explore a mix of ferrite materials that may improve the damping of the 2145MHz mode.

The HOM dampers have yet to undergo mechanical design and manufacture, and studies continue to vary ferrite type and final geometry in order to improve damping of this and the several other modes.

Calculation results of HOM damping are shown in Tables 3, 4.

Table 3: Longitudinal HOM impedances.

Monopole (TM01x)	Frequency (MHz)	Q	Rshunt (kohm)
0	1887	853	0.05
0	1944	232	1
0	1951	47	2.7
0	2036	105	0.1
0	2316	46	0.03
1	1887	852	0.04
1	1944	232	0.03
1	1951	47	0.37
1	2161	65	0.02
1	2474	6.5	0.1

Table 4: Transverse HOM impedances.

Dipole (TM11x)	Frequency (MHz)	Q	Rshunt (ohm/m)
0	1459	372	1076
0	1537.4	101	208
0	1658	54	380
0	1738	119	1222
0	1841	36	3372
0	2063	40	8517
0	2624	35	315
1	1553	21	252
1	1662	49	1075
1	1789	59	7413
1	1876	45	3081
1	2145	192	41664
1	2489	29	619

TUNING OF THE ZERO AND PI MODE

In operations one must control both the π-mode and 0-mode frequencies to allow excitation of the π-mode for bunch lengthening while minimizing excitation of the 0-mode. In addition the π -mode must be able to be tuned for minimum excitation ("parked") or possibly tuned for bunch-shortening studies. These tuning requirements are illustrated in Figure 5.

Because of the tight coupling between the two cells the frequency difference between the 0 and π-modes is nearly constant and can be set during the design and manufacture. Minor adjustments can be made on the bench to set the required separation for operations.

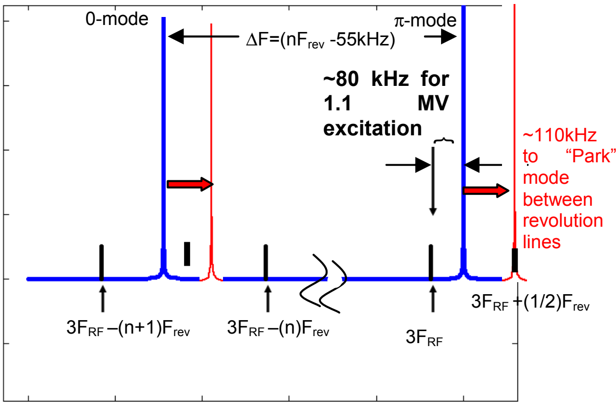

Figure 5: Induced pi-mode voltage as a function of cavity tuning. Frev~380 kHz.

The results of Figure 6 shows the independent tuning of the 0 and π-modes that was achieved.

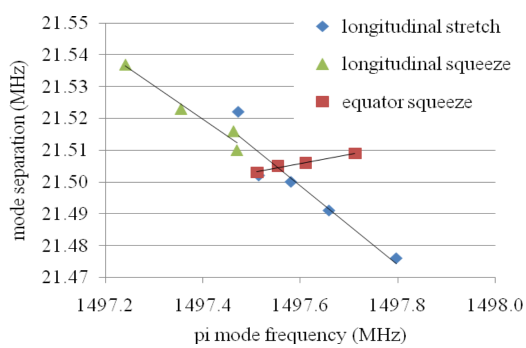

Figure 6: Results of tuning with longitudinal vs. equatorial squeezing, demonstrating frequency adjustment of π-mode and mode separation.

COLD TEST FIRST RESULTS

The first cryotest of the Landau cavity has been performed at Niowave (Figure 7). With small adjustment to the external tuner, the design π-mode frequency of 1499.25 MHz was reached at cryogenic temperatures, with the 0-mode at 1476.93 MHz. The mode separation meets the design requirement and was maintained over approximately 1 MHz tuning range, which covers the bunch lengthening, shortening and parked operational modes. The superconducting transition was observed and the cavity external Q was measured to be $6{\cdot}10^7$. The design value of Q external was $2.6{*}10^8$, a factor of three higher. The Q did not degrade up to an integrated cavity voltage of approximately 400 keV, limited by available RF power. A possible clue to the cause of the extra losses was the measured change in Q external with tuner position, in particular with the parallelism of the tuner. For the cold test a set of three threaded rods was used to move the tuner flange since a motor tuner mechanism is yet to be constructed. The Q external varied by over a factor of two when the tuner flange was tilted. Since the cavity was tested without the HOM dampers installed and stainless steel blank off flanges attached at the end of the thermal transitions a possible explanation is a trapped mode, likely the TE_{11} which can easily be excited by the drive/pickup probes, forming a standing wave and leading to increased losses. Since this first test was conducted from a LHe dewar without recovery (and associated instrumentation) calorimetric data was not available to confirm whether the losses were in the 4K surfaces or thermal transitions and end flange. Further cryotests will verify the static and dynamic heat loads into the liquid helium and liquid nitrogen with higher RF power.

Figure 7: Cold test set up of the 1500MHz cavity.

SUMMARY

A passive SRF 3rd harmonic cavity consisting of two tightly coupled cells has been designed and fabricated for NSLS-II. Initial cold tests of this cavity are very promising. These tests have verified that the cavity frequency and mode separation between the 0 and π-modes can be set at manufacture. Further, the frequency separation can be maintained over wide tuning ranges necessary for operation. Future work includes HOM damper and motorized tuner development.

ACKNOWLEDGEMENT

We have been guided by the work of the Cornell SRF group of Hasan Padamsee. We are supported in this work by the NSLS-II project, especially Ferdinand Willeke. Work supported by DOE contract DE-AC02-98CH1088.

The work at Niowave is funded by DOE SBIR grant DE-FG02-08ER85014.

REFERENCES

[1] J. Keane et al., "Bunch Lengthening Control Using the Fourth Harmonic Cavity in the VUV Ring" PAC 1989, Chicago.

[2] J. M. Byrd et al., "Harmonic Cavities and Longitudinal Beam Stability in Electron Storage Rings" PAC 2001, Chicago.

[3] N. Towne, "Longitudinal Bunch Profiles in NSLS-II with Harmonic Cavity and Ion Clearing Gap" NSLS-II Tech Note # 19, 20061.

[4] T. Yanagisawa et al., "1500 MHz Passive Super-conducting SRF Bunch Lengthening Cavity for the NSLS-II Storage Ring" PAC 2009.

[5] D. G. Myakishev, V. P. Yakovlev, "The New Possibilities of SuperLANS code for Evaluation of Axisymmetric Cavities", 16th PAC1995, Texas, USA, (1995).