DESIGN AND PRELIMINARY TEST OF THE 1500 MHZ NSLS-II PASSIVE SUPERCONDUCTING RF CAVITY

J. Rose*, W. Gash, B. Kosciuk, V. Ravindranath, B. Sikora, S. Sharma, N. Towne
Brookhaven National Laboratory (BNL), Upton, NY 11973, USA
T. L. Grimm, C. H. Boulware, C. Krizmanich, B. Kuhlman, N. Miller, B. Siegel, M. Winowski
Niowave, Inc., 1012 N. Walnut Lansing, MI 48906, 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. Earlier work [1] described the design alternatives and the geometry selected for a copper prototype. We subsequently have iterated the design to lower the R/Q of the cavity and to increase the diameter of the beam pipe ferrite HOM dampers to reduce the wakefield heating. A niobium cavity and full cryomodule including LN2 shield, magnetic shield and insulating vacuum vessel have been fabricated and installed.

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 [2, 3] of increasing the lifetime is to use a harmonic cavity to flatten the potential well and lengthen the 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 [4]. 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. However having the two coupled cells results in two fundamental modes, 0 and π. The unwanted 0-mode cannot be damped since it is too close to the π-mode. 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 the 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 [4], an R/Q of the 0-mode of << 1 ohm and a large beam pipe diameter to reduce the wakefield heating of the ferrite mode dampers to acceptable levels. These goals were achieved by taking the conceptual cavity design [1] 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.

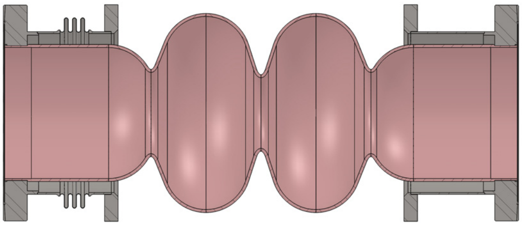

Figure 1: 1500 MHz cavity geometry

Table 2: NSLS-II harmonic cavity parameters

Freq(π-mode)	MHz	1499.25
R/Q (Pi)	▯	88
Accelerating Voltage	MV	1.0
Freq (0-mode)	MHz	1478.03
R/Q (zero)	▯	0.15

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*rose@bnl.gov

CALCULATION OF HOMS

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

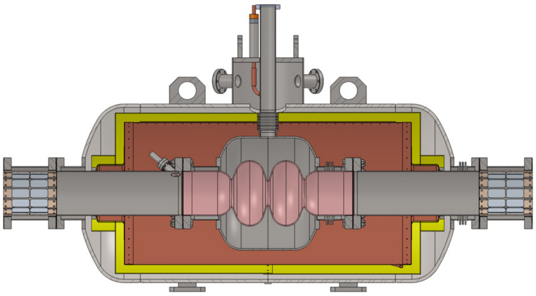

Figure 2: Geometry of NSLS-II 3rd harmonic cryomodule.

The 2D codes CLANS and CLANS2 [5] were used to calculate the longitudinal and transverse HOMs. Calculation results of HOM damping are shown in Tables 2, 3.

Table 2: Longitudinal HOM impedances

Frequency (MHz)	Q	R/Q (Ω)	f R (kΩ GHz)
2739.3	88.341	23.83	5.77
1944.	233.76	1.663	0.76
2686.65	39.687	4.346	0.46
2482.15	43.054	3.68	0.39
2313.8	50.121	2.548	0.3
2036.31	121.96	0.88	0.22
2037.95	36.32	1.674	0.12
2716.26	38.439	1.093	0.11

Table 3: Transverse HOM impedances

Frequency (MHz)	Q	R/Q (Ω)	R (kΩ/m)
2145.09	305.4	196.	59.85
1784.18	66.9	109.3	7.31
2033.48	36.2	138.	4.99
1966.38	46.4	106.8	4.95
1871.25	65.8	70.8	4.65
1835.16	45.4	69.1	3.14
2084.72	31.5	45.	1.42
1736.07	141.7	9.1	1.29

MECHANICAL DESIGN AND FABRICATION

Dies were fabricated in order to manufacture the niobium components from sheet metal. The beam tubes were then brazed to stainless-steel flanges and the bellows and tube ends of the helium vessel were TIG welded on. After the components were formed the separate pieces were electron-beam welded together to form the full cavity structure. After the cavity was fabricated, the niobium RF surface underwent a bulk chemical etch using Buffered Chemical Polish (BCP). At this point the tuning of the 0 and π-modes took place. This tuning is discussed in the next section. After the tuning the remainder of the stainless steel helium vessel was TIG welded and a light chemical etch took place. After the etch the cavity was high-pressure rinsed. The cold mass was then assembled in the class 100 clean room.

The cold mass was then suspended from the conning tower and cryomodule assembly began. Superinsulation was installed around the helium vessel, then the copper liquid nitrogen shield was installed. After more layers of superinsulation were installed the mu metal magnetic shield was attached. After additional superinsulation was installed the outer vacuum vessel was TIG welded to finalize the cryomodule. During cryomodule assembly all necessary sensors and antennas were installed and all vacuum boundaries were leak checked.

After the cryomodule was completely assembled the entire structure re-entered the clean room. At this point the cavity was pumped down to its ultra-high vacuum and the vacuum vessel was pumped down to its rough vacuum. The entire cryomodule assembly was then removed from the clean room and prepared for the cold test as shown in Figure 3.

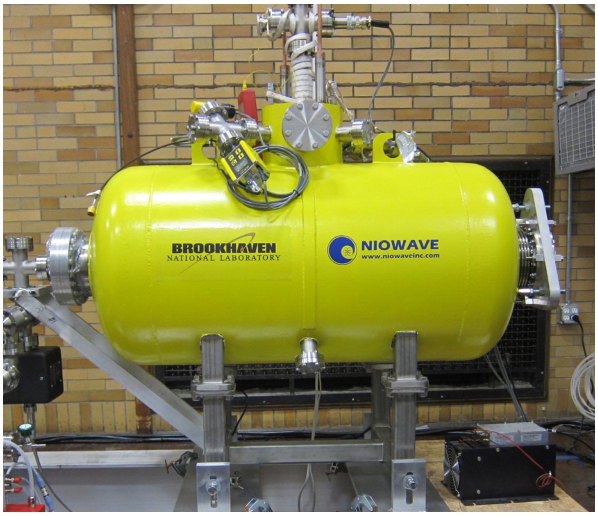

Figure 3: Cold test set up of 1500MHz cavity

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 4.

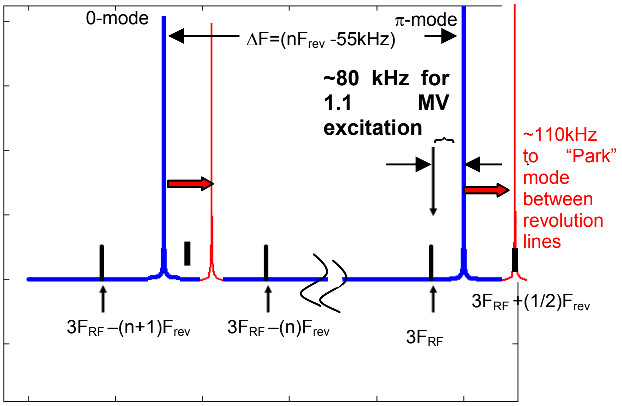

Figure 4: Induced pi-mode voltage as a function of cavity tuning. Frev~380 kHz

Because of the tight coupling between the two cells the frequency 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. The tuning fixture for tuning on the bench is shown in Figure 5 and an example of the elastic tuning range is shown in Figure 6. The results of Figure 6 show the independent tuning of the 0 and π-modes that is required.

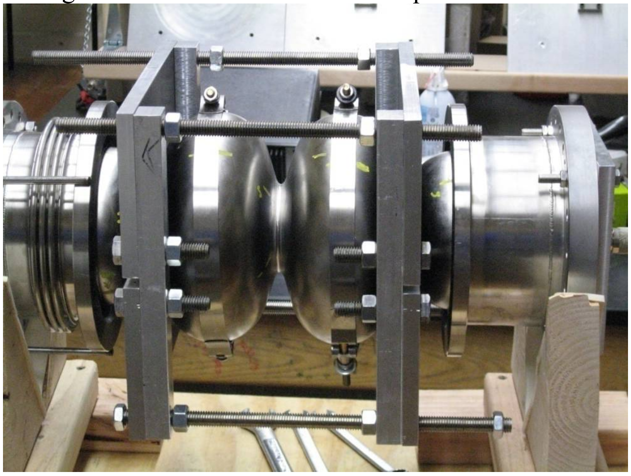

Figure 5: Tuning fixture for longitudinal and equatorial tuning installed on the finished niobium cavity.

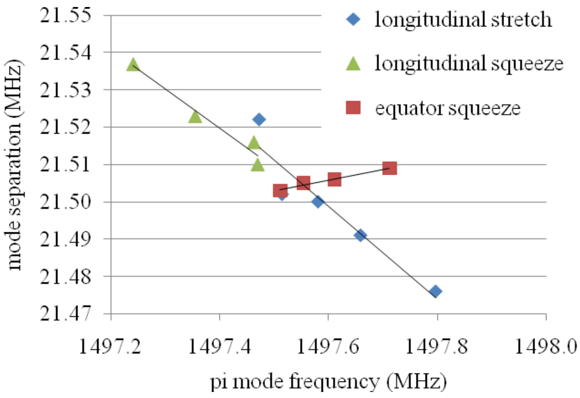

Figure 6: Results of tuning with longitudinal vs. equatorial squeezing, demonstrating adjustment of π-mode and mode separation.

COLD TEST FIRST RESULTS

The first cryotest of the Landau cavity has been performed at Niowave. 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 Q was conditioned up to $6\cdot10^7$. The Q did not degrade up to an integrated cavity voltage of approximately 400 keV, limited by available RF power. Further cryotests will verify the static and dynamic heat loads into the liquid helium and liquid nitrogen with higher RF power.

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.

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