SUPERCONDUCTING PROTOTYPE CAVITIES FOR THE SPALLATION NEUTRON SOURCE (SNS) PROJECT *

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Abstract

The Spallation Neutron Source project includes a superconducting linac section in the energy range from 186 MeV to 1000 MeV. For this energy range two types of cavities are needed with geometrical β values of β=0.61 and β=0.81. An aggressive cavity prototyping program is being pursued at Jefferson Lab, which calls for fabricating and testing four β=0.61 cavities and two β=0.81 cavities. Both types consist of six cells made from high purity niobium and feature one HOM coupler of the TESLA type on each beam pipe and a port for a high power coaxial input coupler. Three of the four β=0.61 cavities are being used for a cryomodule test starting in May 2002. At this time four medium beta cavities and one high beta cavity have been completed and tested at JLab. In addition, the three medium beta cavities for the prototype cryomodule have been equipped with the integrated Ti-Helium vessel, successfully retested and assembled into a cavity string. The tests on the β=0.61 and the β=0.81 cavities exceeded the design values for gradient and Q value: E_{acc} = 10.1 MV/m and $Q = 5\times10^9$ at 2.1K for β=0.61 and E_{acc} = 12.3 MV/m and $Q = 5\times10^9$ at 2.1 K for β=0.81. This paper will describe the test results obtained with the various cavities, some aspects of the HOM damping at cryogenic temperatures, results from microphonics and Lorentz force detuning tests and the cavity string assembly.

1 FABRICATION

The fabrication procedure for the cavities was described in [1]. Tuning to a "flat" field profile followed a 20 µm external chemistry. Two of the three cavities for the prototype cryomodule have been heat treated for 6 h at 800^0C – a typical temperature to remove hydrogen that can cause "Q-disease". The cavities had to be tuned again and at that point they appeared to be extremely "soft", as they started yielding with about 170 kg of axial force, which correspond to a frequency change of about 500 kHz. The low yielding point was confirmed by tests made on samples. However the reasons are not completely understood and are still under investigation. Internal buffered chemical polishing (BCP) in JLab's closed chemistry system with ~ 120 µm material removal and subsequent high pressure ultrapure water rinsing for 2 h completed the final surface treatment.

After drying for several hours the cavities were assembled in the clean room. Unfortunately, problems with the $AlMg_3$ seals were found since the cavities could not be sealed at room temperature. To avoid further delays, it was decided to adapt the flanges to use indium seals. The issue regarding the seal with $AlMg_3$ gaskets is still under investigation.

Table 1: β=0.61 SNS cavities frequency and field flatness after welding.

Cavity ID	Frequency	Field Flatness
061SNS002	804.043	23%
061SNS003	804.191	32%
061SNS004	804.152	50%

Figure 1: SNS β=0.61 used in the prototype cryomodule.

After being tested in the vertical dewars, the cavities have been tuned to the final frequency.

The welding of the helium vessel started with the tack weld of the first head, followed by the cylinder. A three-arm spider is then bolted at the centre of the cavity and then welded to the cylinder. The spider is used to support the cavity against transversal forces. The second helium vessel head is then tack welded to the cavity end dish and to the cylinder. The cavity was then set horizontally on a rotating fixture for full welding, using skip-welding technique (figure 2). Each helium vessel is equipped with one heater and two diodes for temperature measurement. In one helium vessel per cryomodule there are also two liquid level probes.

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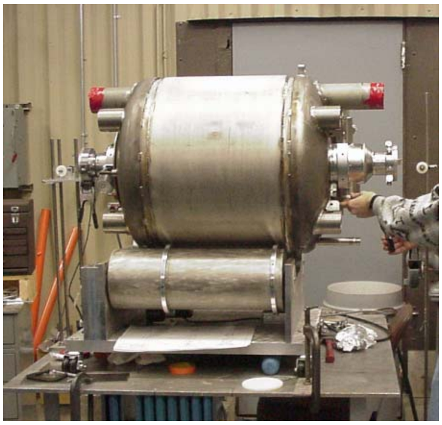


Figure 2: Helium vessel welding on the SNS β=0.61 cavity.

Several field profile measurements have been done during each step of the helium vessel welding to monitor any variation in the cavity's frequency and field profile. The frequency decreased, on the average, by about 70 kHz, and the final field flatness was typically 10%.

After welding of the helium vessel, an additional 20 μm of material were removed from the internal surface of the cavity with BCP, followed by high pressure ultrapure water rinsing for 2 h. The cavities were then assembled in the clean room and tested in the vertical dewar.

2 VERTICAL TEST RESULTS

The results of the vertical test for the three six-cells β=0.61 cavity at 2.17 K before welding the He vessels are shown in figure 3. The cavities had a Q_0 at low field of about 1.7×10^{10}. The average gradient at a Q_0 $=5\times10^9$ is 14.2 MV/m. All the cavities had about 20 min of RF processing and they were limited by field emission.

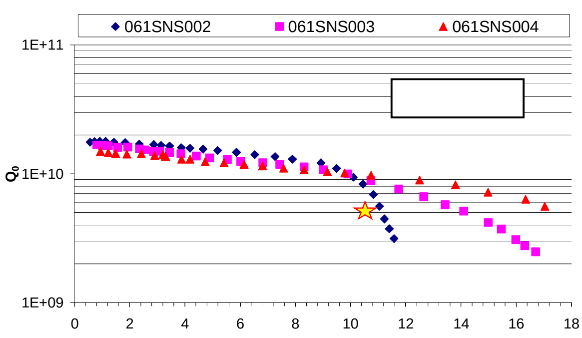
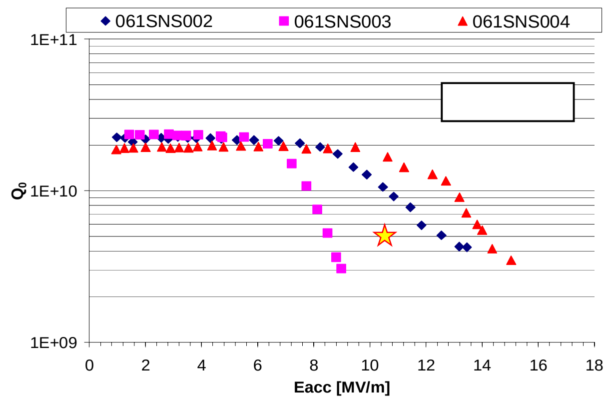


Figure 3: SNS β=0.61 vertical tests results before welding the helium vessels.

The slope in the Q_0 vs. E_{acc} is due to the temperature being too close to the lambda point. The results for the six-cells β=0.81 cavity were presented in a previous paper [1]. The cavity that was not heat-treated (061SNS004) was warmed-up and kept to 100K for 24 h after the RF test at 2.17K. The subsequent cool down to 2K showed "Q-disease". This cavity was subsequently heat-treated at 600^0C for 10 h prior to attaching the helium vessel. It was also verified that the cavity was stiffer then the ones that had been heat-treated at 800 C, confirming the measurements done on samples.

The results at 2.1K after welding the He vessel are shown in figure 4. The Q_0 at low field was about 2×10^{10}. The average gradient Q_0 $=5\times10^9$ is 11.7 MV/m, with one cavity not reaching the target value. All the cavities had about 30 min of RF processing. No further improvement was achieved with helium processing. Cavity #4 was then warmed-up to 100K for 24 h and after cool-down to 2.1K the Q_0 was 1.9×10^{10}, proving the effectiveness of the heat-treatment at lower temperature.

Figure 4: SNS β=0.61 vertical tests results after welding



the helium vessels.

The accelerating gradient after welding the helium vessel decreased by about 20%; this seems to indicate that contamination during helium vessel welding needs to be controlled better and possibly more material must be removed once production of the cryomodules starts.

3 MECHANICAL ANALYSIS

3.1 Lorentz force detuning

The tuner frame had been mounted on cavity #4 helium vessel so that the Lorentz force coefficient for a cavity with boundary conditions close to the operational ones could be measured. The results for two measurements are shown in figure 5 along with the results obtained from cavity #2 with the helium vessel only. The Lorentz force coefficient for the cavity with helium vessel and tuner is about –3 $Hz/(MV/m)^2$ while the value with the helium vessel alone is about -7 $Hz/(MV/m)^2$. The values obtained with the finite element calculations (as described in [1]) for the cavity with helium vessel and tuner are –3.6 $Hz/(MV/m)^2$, for an estimated tuner stiffness of 2×10^6 kg/m, and –2.9 $Hz/(MV/m)^2$ assuming a tuner stiffness of 3.4×10^6 kg/m. These values are very close to the maximum possible value of –3 $Hz/(MV/m)^2$ required by the SNS operation. It has been decided to install piezoelectric devices on the tuner frame to help compensating frequency shifts induced both by the Lorentz force and by microphonics.

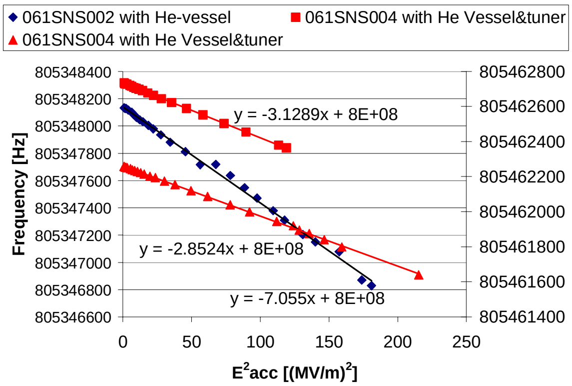


Figure 5: SNS β=0.61 frequency vs. E_{acc}^2.

3.2 Microphonics

A measurement of the frequency shift due to microphonics was done on the first β=0.61 prototype cavity integrated in the He vessel and with a mock-up tuner. The test was done with the cavity at 2.1K in the vertical dewar, as described in [1]. As can be seen in figure 6, the FWHM of the histograms curve is about 12 Hz, which is an acceptable value for the SNS operation.

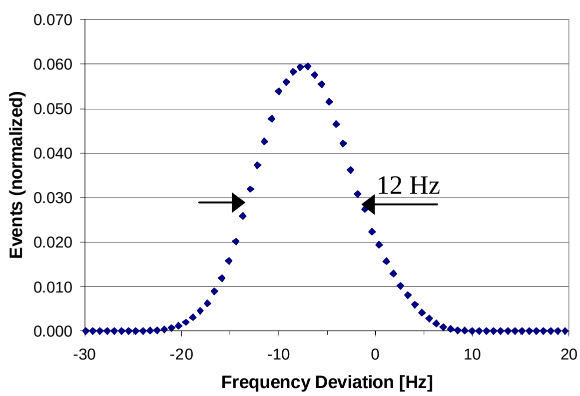


Figure 6: Frequency shift due to microphonics measured on the β=0.61 cavity with He vessel and mock-up tuner.

4 HIGH ORDER MODES

A preliminary measurement of the Q_{ext} of the dangerous HOM's has been done on cavity #3 at 2.1 K. These values are consistent with the measurements at room temperature.

Table 2: Measured Q_{ext} and frequencies for the dangerous modes on the β=0.61 cavity.

Mode	**Q_{ext} @ FPC side**	**Q_{ext} @ probe side**
TM_{021}-5π/6 (#31)	1.2×10^5	4×10^5
TM_{021}-π (#32)	8.5×10^5	1.2×10^4

The Q_{ext} for the fundamental mode was 2.6×10^{13} for the HOM coupler at the fundamental power coupler side and 1.3×10^{11} for the one at the probe side.

5 STRING ASSEMBLY

After the RF test in the vertical dewar, each cavity has then been processed through 20' of BCP, 1 h of high pressure rinsing and drying in the class 100 clean room at atmospheric pressure. One cavity per day was processed and assembled with auxiliary parts such as valves, couplers and field probes. After three days the three-cavity string was assembled, with stainless steel bellows in between and fundamental power couplers attached.

Figure 7: SNS β=0.61 three-cavity string assembled in the clean room.

6 SUMMARY

The three SNS cavities for the first cryomodule had been fully tested reaching the Q_0 and E_{acc} requirements. They have been integrated in the helium vessels, tested again at 2.1K and finally assembled into the cavity string. The requirements on the Lorentz force coefficient and microphonics seems to be under control, especially because piezo-tuners are going to be installed. The cryomodule has been assembled and it will be under test at the time of the conference.

7 REFERENCES

[1] G. Ciovati et al., "Superconducting Prototype Cavities for the Spallation Neutron Source (SNS) Project", 10th RF Superconductivity Workshop, Tsukuba, Sep. 6-11, 2001.

8 ACKNOWLEDGEMENT

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