BNL 56 MHz HOM DAMPER FABRICATION AT JLAB

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Abstract

The Higher-Order Mode (HOM) Dampers for the Relativistic Heavy-Ion Collider's (RHIC) 56 MHz cavity at Brookhaven National Laboratory (BNL) are currently being fabricated at JLab. The coaxial damper is primarily constructed with high RRR niobium, with a combination of niobium and sapphire rings as the filter assembly. Several design changes have been made with respect to the performance of a prototype damper – also fabricated at JLab – which was found to quench at low power. The production dampers are being tuned and tested in the JLab vertical test area (VTA) prior to delivery. Two HOM dampers will be delivered to BNL; they are to be used in the RHIC in November, 2015. This paper outlines the challenges faced in the fabrication and tuning process.

INTRODUCTION

Work on five HOM dampers was started at Niowave Inc. in early 2014. The majority of the parts were fabricated at Niowave, as was part of the assembly. The project was transferred to JLab in July 2014. The number of dampers to be delivered was revised to two out of the original five, to allow for installation during RHIC's 2015 shutdown period (July – November). The two dampers would fit at the 225 degree and 270 degree positions on the RHIC cavity; they are named BNL01 and BNL03 respectively. The following tasks were to be carried out at JLab:

- Determine an assembly and fabrication sequence and plan, utilizing parts and assemblies received from Niowave
- Fabricate other required components
- Integrate design changes from BNL
- Conduct required welding, chemistry and inspection
- Tune fabricated dampers, including tests at 4K in the JLab vertical test area (VTA)
- Perform pressure and leak checks as required

The two dampers are scheduled to be delivered to BNL in late September, 2015.

DESIGN FEATURES

A cut-away view of the HOM damper is shown in Fig. 1. The Loop resides inside the cavity and acts as the coupling mechanism. The damper is attached to the cavity via the NbTi flange.

Cooling

The Main Inductor connects to the Loop at the cavity end of the damper, and supports the Filter Assembly at the other end. The Inductor acts as the primary cooling mechanism for the damper. Essentially, it is a Niobium tube, through which a copper rod runs. The rod is connected via an interference fit at the Loop (the area of highest heat generation) and is immersed in flowing liquid helium at the Cooling Turret [1]. Channels in the

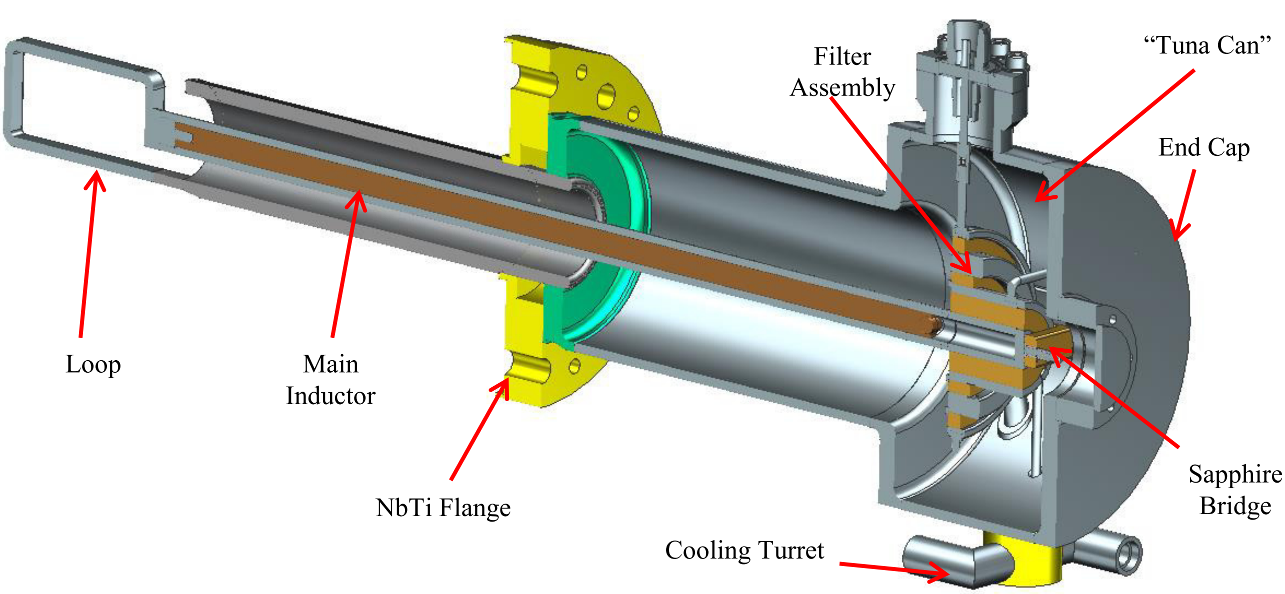

Figure 1: Cut-away view of the prototype damper, showing main components.

NbTi flange are also connected to the helium flow, acting as a secondary cooling mechanism. This design remained unchanged from the prototype HOM damper, also built at JLab in 2013,

Filter Assembly

The Filter Assembly is a capacitor consisting of three Niobium and three sapphire rings. The Niobium rings are connected to the outer shell of the damper via three inductor rods, and to an N-Type connector via another inductor rod [1]. The sapphire rings are held in place by means of Niobium 'stoppers', which were EBW to the Niobium rings (Fig. 2). To prevent arcing, the corners of the stoppers were rounded using a silicon carbide abrasive, and then acid etched via a swab.

Figure 2: Filter Assembly, showing the Nb 'stoppers' and Inductor Rods.

TUNING

The dampers are tuned by moving the Filter Assembly axially along the Main Inductor. The position of the former is restricted by the presence of the Inductor Rods, which connect it to the inside of the 'Tuna Can'. An antenna is used to couple to the Loop, with the damper positioned vertically (Fig. 3). The S21 curve is measured with a network analyser. The main feature is the first notch in the S21 curve, which should ideally be at 56.3 MHz. Figure 4 shows the location of the notch in the tuned prototype damper [1].

In its un-tuned state, the Filter Assembly rests flush with the end of the Main Inductor. Moving the Filter Assembly along the Main Inductor, away from the Loop, lowers the frequency of the notch. The Filter Assembly was designed to move up to 3mm in order to achieve the tuning.

In the prototype, the un-tuned notch frequency was found to be 61.8 MHz [2]. The frequency was brought down to the required 56.3 MHz by the subsequent tuning. However, the new dampers did not behave the same way, with BNL01 having a starting frequency of 69.2 MHz and BNL03 having 69.7 MHz. When the End Cap was positioned over the Tuna Can, the frequency was found to decrease ~ 2.0 MHz for both dampers; this is not believed to represent the actual change which will occur when the End Caps are welded to the assembly.

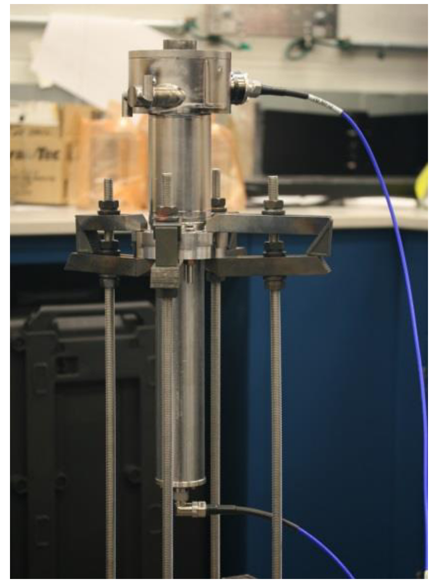

Figure 3: Tuning setup for BNL01.

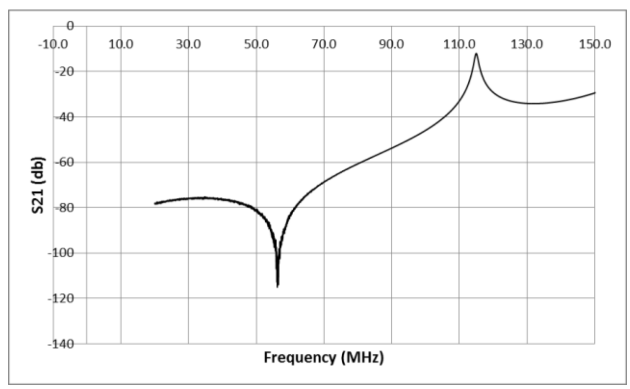

Figure 4: Network analyser output from tuning process of the prototype [1]. Target is first notch being set to 56.3 MHz.

Sapphire Bridge

The tuned Filter Assembly is held in place via the Sapphire Bridge, which is attached to the inner Niobium ring (Fig. 5). A #2-56 threaded NbTi rod extends down through the bridge, making contact with the end of the Main Inductor, and locking the Filter Assembly in place.

Originally, the NbTi threaded rod was designed to not only hold the Filter Assembly in place, but also change its position by pressing down on the Main Inductor. Upon testing of this function, it was found that even a small amount of torque put on the small threads caused the nut to gall on to the threaded rod, effectively destroying the

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bridge's ability to adapt to different tuning positions. It was decided that the nut on the threaded rod would only be tightened at the final tuning step, with no intention of loosening it again.

As the Filter Assemblies had to be moved an excessively large distance, the original threaded NbTi rod was no longer large enough to serve its purpose.

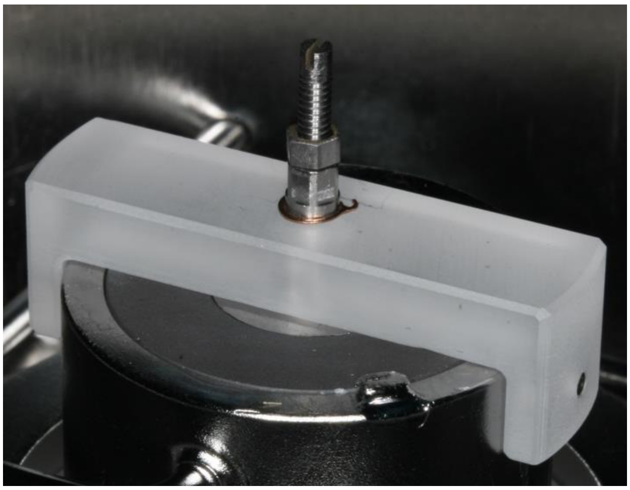

Figure 5: Sapphire Bridge positioned on the Filter Assembly in BNL03. The damper is shown in its un-tuned state.

End Cap Modification

The increased movement of the Filter Assembly also meant that the Sapphire Bridge now interfered with the End Cap, which closes the Tuna Can. As such, counter-bores were introduced to the End Cap to fit the Sapphire Bridge.

In the case of BNL01, it was found that the counter-bore, by means of increasing the distance from the top of the Filter Assembly to the inner wall of the End Cap directly opposite, lowered the notch frequency by 1.4 MHz.

A series of different counter-bore sizes were tested before a final version with a diameter of 1.75 inches was chosen. Figure 6 shows a comparison of the original and modified end caps. New caps were fabricated in order to extend the depth of the counter-bore. The new design also called for a cap to be welded on to the end of the turret, so the threaded holes were discarded.

The effect of the different caps was examined by tuning BNL03. A counter-bored cap ('CB Cap') was used for the test. The cap contained two counter-bores; the first being with a diameter of 2.5 inches and a depth of 0.15 inches, and the second (within the first counter-bore) with a diameter of 1.5 inches and a further depth of 0.075 inches. The results of the tuning (with a range of 0 – 3 mm) can be seen in Figure 7. On average, the counter-bored cap was found to reduce the notch frequency by 1.1 MHz

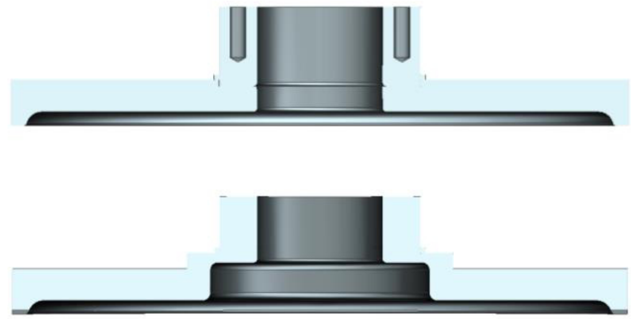

Figure 6: The original End Cap (top) and modified version (bottom).

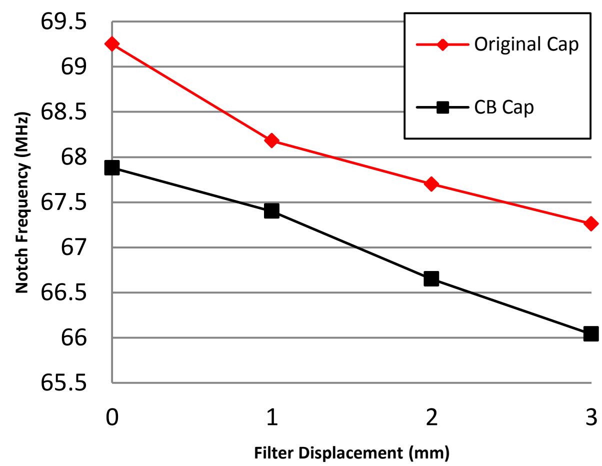

Figure 7: Comparison of original and counter-bored (CB) cap for BNL03 tuning.

4K Testing

BNL03 was tested in the vertical test assembly (VTA) at JLab to test the effects of cooling on the damper tuning. The damper was cooled by Helium gas, without being immersed in the liquid, to a temperature of 4K. It was found that the notch frequency decreased by ~1.0 MHz due to the cooling. However, the End Cap was not welded on to the assembly at this stage, and only clamped together; a more significant change is likely with the End Cap being welded. In addition, the threaded NbTi rod had not locked the Filter Assembly into place, and the decrease in notch frequency was maintained after it was warmed up. It was decided that the effects of cooling on the damper were negligible to the notch frequency.

BNL01 Tuning

The Modified End Cap was used in the tuning for BNL01. The previously positioned displacement of 5.8mm had to be altered to 11.5mm to reach the required notch frequency (Fig. 8).

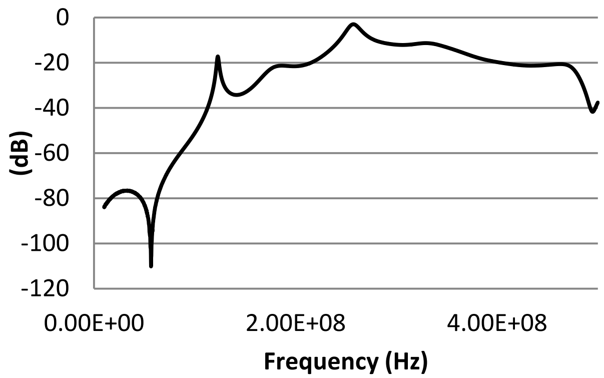

Figure 8: S21 feedback for BNL01 at a tuning displacement of 11.5mm, showing a notch frequency of 56.3 MHz.

BNL03 Tuning

The BNL03 damper was also tuned using the modified End Cap. The effect of the cap was not as pronounced as had been found in BNL01. Figure 9 shows the effect of moving the Filter Assembly from its un-tuned position, in relation to the notch frequency. Figure 10 shows the notch at a filter displacement of 12mm.

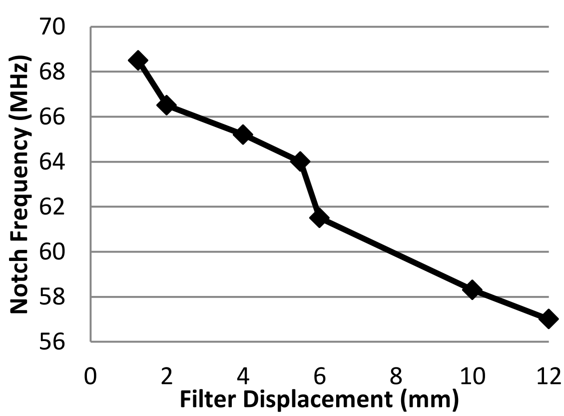

Figure 9: Notch frequencies of BNL03 while tuning.

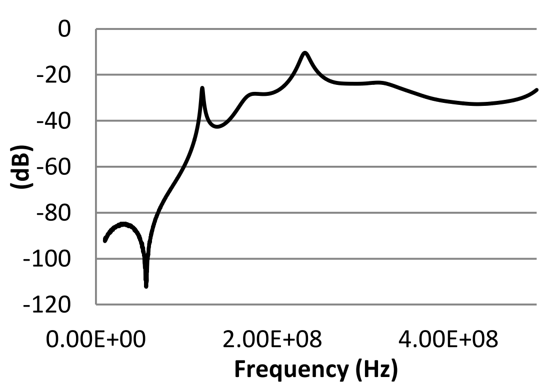

Figure 10: S21 feedback for BNL03 at a tuning displacement of 12mm, showing a frequency of 57.0 MHz.

Tuning Summary

Both dampers required far larger Filter Assembly displacements than originally planned. The prototype damper required ~3mm, while BNL01 and BNL03 required 11.5mm and 12mm respectively. As such, the physical limitations of the Filter Assembly and Inductor Rods were pushed to the limit. Figure 11 shows the effect of tuning on the Inductor Rods in BNL01. Several modifications are required to safely complete the final welds for the dampers:

1. Material must be removed from the inside of the counter-bores in the modified End Caps. Currently, there is only a ~1mm gap between the top of the Sapphire Bridge and the End Cap. This gap could close further – or even completely – after the End Cap is welded.
2. The threaded NbTi rod used to fix the position of the Filter Assembly in place has to be lengthened, from an original total length of 0.60 inches to 1.01 inches.

Figure 11: Filter Assembly in BNL03 after tuning.

REMAINING FABRICATION TASKS

Cooling Line Tubing

A series of titanium tubes will be welded on to the cooling turret and flange. These will mate to existing helium lines in the RHIC cryomodule. Explosion bonded Titanium to Stainless Steel transitions will be welded to the ends of the tubes. As these will all be TIG welds, the Titanium tubing and inner chamber of the damper itself will be purged with Argon.

Pressure and Leak Checks

The Titanium lines will be pressurized to 37psig to mimic the worst possible pressure differential over the NbTi Flange. The pressure will use helium gas, in order to perform a leak check simultaneously.

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The entire damper is to be leak checked after the final End Cap Disc is welded on. Of particular importance is the indium seal between the N-Connector flange and the Tuna Can. In the prototype, this was found to leak at a rate of 1×10^{-4} Torr L/s. This was acceptable as the previous design did not have this section of the damper exposed to cavity vacuum. This is no longer the case with the new design, and the seal must work to 1×10^{-12} Torr L/s. To ensure a proper seal, the following chemistry procedure was developed at BNL for the indium gaskets:

1. Etch gasket with 5% HCl acid solution for 1 minute
2. Rinse with DI water, followed by Acetone
3. Blow dry with ultra-pure Nitrogen and install immediately.

Cleaning and Chemistry

The damper assemblies are to be UHV cleaned with DI water after each of the upcoming assembly steps. The final step before shipping will be to conduct a 15 micron acid etch on the cavity side of the damper, from the Loop to the NbTi Flange. The sealing surface of the flange will be protected by using DyMax™ masking agent.

CONCLUSION

The two production HOM Dampers, BNL01 and BNL03, have been fabricated and tuned at JLab. The final welds, leak checking and cleaning are yet to be completed. The dampers are scheduled to be delivered to BNL in late September, 2015

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