RECENT PROGRESS ON HIGH-CURRENT SRF CAVITIES AT JLAB *

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Abstract

JLab has designed and fabricated several prototype SRF cavities with cell shapes optimized for high current beams and with strong damping of unwanted higher order modes. We report on the latest test results of these cavities and on developments of concepts for new variants optimized for particular applications such as light sources and high-power proton accelerators, including betas less than one. We also report on progress towards a first beam test of this design in the recirculation loop of the JLab ERL based FEL. With growing interest worldwide in applications of SRF for high-average power electron and hadron machines, a practical test of these concepts is highly desirable. We plan to package two prototype cavities in a de-mountable cryomodule for temporary installation into the JLab FEL for testing with RF and beam. This will allow verification of all critical design and operational parameters paving the way to a full-scale prototype cryomodule.

INTRODUCTION

JLab has produced three full-featured five-cell prototype cavities, two at 1.5 GHz, figure 1, and one at 750 MHz, as well as two single-cell cavities and a "bare" 5-cell large-grain prototype. [1] The program for which these cavities were originally produced has been terminated, however there is continued interest in their performance for other applications. We have continued to develop them, albeit at a slow pace, to show utility for other projects and to test new processes, including electro-polishing and centrifugal barrel polishing.

RECENT ACTIVITIES

Recently there has been a resurgence of interest at JLab in the high-current work. This has been sparked by interest in performing a beam test of the 1.5 GHz prototypes in the JLab FEL, and by the possibility of using the low frequency version for a high brightness injector for fourth generation light sources, or as a candidate design for high-power CW proton sources.

Cavity tuning

The 1.5 GHz cavities as produced had good field flatness and mechanical tolerances but were several MHz high in frequency. Estimates for frequency shift after chemical polishing proved to be too generous, possibly because of the unique cell shape of these cavities, so the frequency did not drop as much as expected after bulk material removal.

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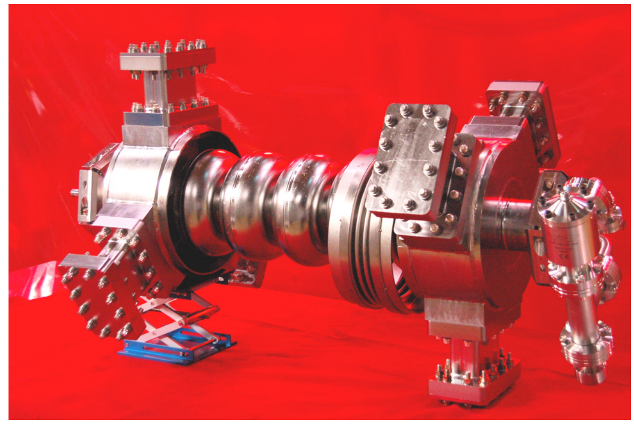

Fig.1. 1.5 GHz 5-cell high-current cavity ready to test.

Tuning the cavities down in frequency requires longitudinal compression of the cells. Since this cavity shape has vertical walls there is a risk of the cells becoming re-entrant if tuning force is applied close to the iris. Thus it is desirable to apply the tuning force at the outer part of the cell, which is considerably stiffer. Furthermore the end cells are significantly obstructed by the wrap-around helium vessel ends. This required segmented off-set tuning plates to be fabricated, see figure 2. Tuning of the two prototypes will be attempted soon.

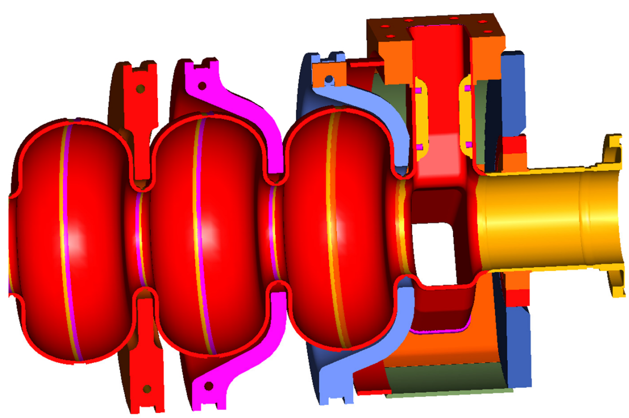

Fig. 2. Standard and offset tuning plates for the HC cavity.

Cavity testing

Several cavity tests have been performed on high-current cavities in the last year. The 1.5 GHz 5-cell "bare" prototype, which has no helium vessel or waveguides, was electropolished in an attempt to improve performance after initial chemistry. Unfortunately the performance was degraded and did not exceed the previous best initial performance of 21.6 MV/m. Subsequent optical inspection revealed a number of suspicious surface features so the decision was made to try to recover the surface by centrifugal barrel polishing (CBP), which is a mechanical process for material removal that has been shown to be successful in other cavities. The 5-cell cavity was polished using three grades of media resulting in a smooth looking semi-glossy surface. Unfortunately one cell was distorted when a fixture became loose during the polishing. The damaged cell was retuned and the cavity was processed and tested anyway. It recovered reasonably well, reaching a quench limit of 20 MV/m but with a good Q (>10^{10} at 2K), and no high-field Q-slope, see figure 3. The damaged cell has now been cut out and will be replaced by a fresh cell in the near future.

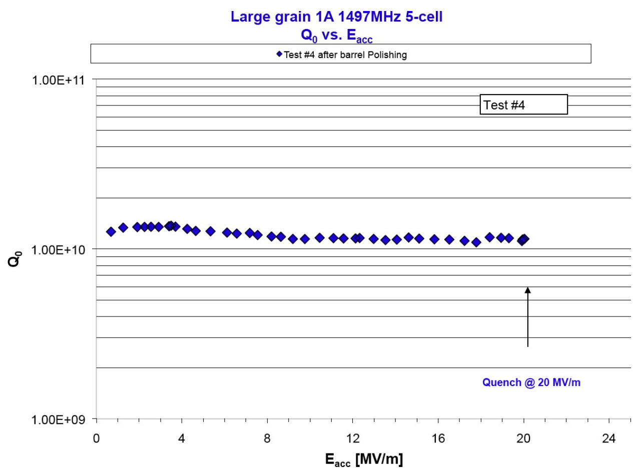

Fig. 3. Test result of 5-cell 1.5 GHz cavity after CBP.

Low frequency cavity test

The 750 MHz 5-cell cavity never reached vertical testing in the original program but was recently retrieved from storage and processed. Due to the unusual shape and large size it required special tooling for chemistry and high-pressure rinse and a unique three-sided cage for handling and manipulation, figure 4. The cavity is too large to fit in any existing tuning bench at JLab but fortunately it was acceptably field flat as fabricated. Special tooling will be required to mount the cavity in the vacuum furnace for hydrogen degassing so initial tests were done without heat treatment but with rapid cool down to avoid the risk of Q-disease. Initial processing was ~100µm of material removal by BCP followed by one cycle of high pressure rinsing. Initial results are encouraging with performance similar to the single-cell 750 MHz prototype [2]. Maximum field was 22 MV/m, figure 5, limited by field emission. Q_o was reasonable at 2K. Some multipacting was seen initially at about 3 MV/m but processed quickly. The in-cell multipacting barrier was seen between about 10-14 MV/m but processed away. Further tests are planned for this cavity.

Coupler developments

Two prototype WR650 waveguide windows have been successfully tested to over 60 kW, and several high power coupler concepts have been developed. However the JLab FEL program is moving in the direction of lower current, higher energy machines so the development has shifted towards simpler lower-power couplers.

HOM loads

Similarly concepts for high-power loads were developed but at low current these can be greatly simplified, however good HOM damping over a broad frequency range is still required. Development has concentrated on finding materials with broadband absorption characteristics over a suitably wide range of temperatures. Candidate materials have been identified and prototype low-power broadband loads have been built and tested, see figure 6.

Fig. 4. 750 MHz high-current cavity in preparation.

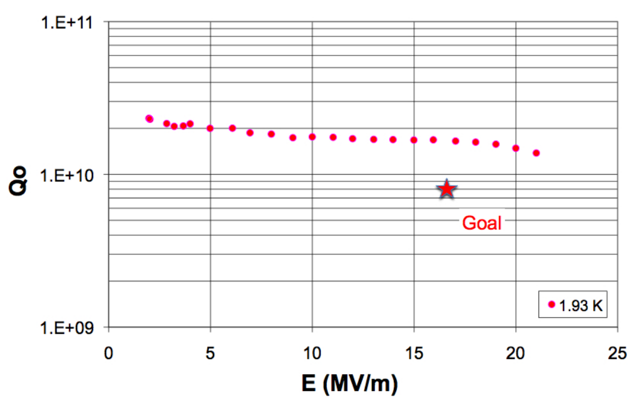

Fig. 5. First test result of 750 MHz five-cell cavity.

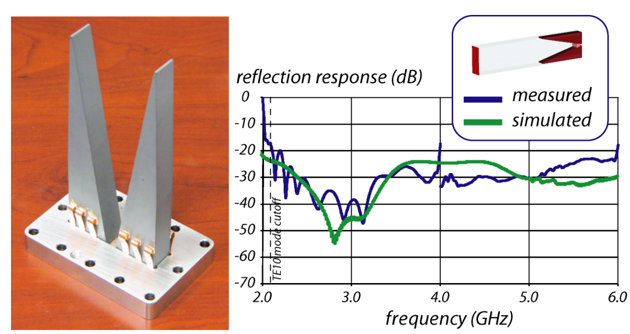

Fig.6. Broadband low-power HOM load prototype.

CRYOMODULE DEVELOPMENT

A complete conceptual design of a test cryomodule has been developed based on components from the original CEBAF module, see figure 7. The concept uses a space-frame design to provide support and alignment of the cold mass similar to that used for the SNS and 12 GeV upgrade cryomodules, see figure 8. A test of this design with beam would validate the HOM damping properties of the cavities and demonstrate operability in a configuration that is very close to a production-ready environment. Plans for such a test are presently under discussion. This design could be used for a fourth generation light source.

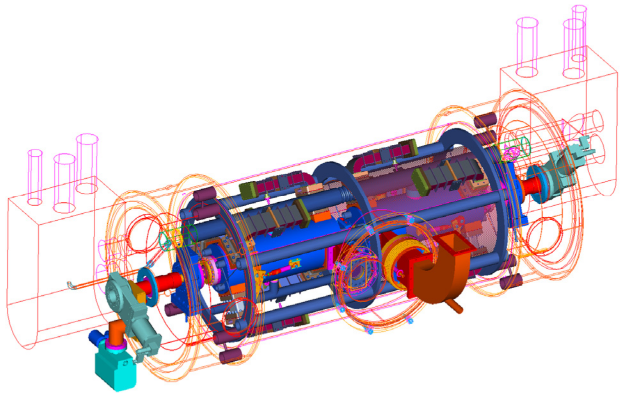

Fig. 7. Concept for a high-current test cryounit.

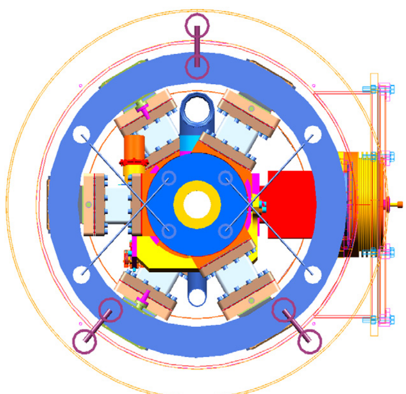

Fig.8. Cross section of high-current test cryounit showing helium circuit, space frame and support rods.

NEW APPLICATIONS

There is increasing interest in high-current capable cavities and cryomodules for hadron machines such as proton drivers (e.g. for neutrino physics), spallation neutron sources, and accelerator driven subcritical reactors. Many of these machines are proposed to be CW or high duty factor with high average currents. Prospects are good that such machines could be built in the near future [3]. The JLab high current cavity concept could be a good candidate for such machines. It has a large bore, which is beneficial for minimizing beam halo interception as well as providing good cell-to-cell coupling. This tends to minimize distortion of the field flatness due to manufacturing tolerances or other detuning effects. However a smaller bore could yield greater efficiency, which is very important for CW applications, and there is potential for a tradeoff in these respects.

Different Frequencies

The concept can easily be scaled to different frequencies and this exercise has been performed for several potential applications from 650 MHz to 2.45 GHz. However it is not always optimal to simply do a geometric scaling as the resulting iris diameter may be unnecessarily large at the low end and unreasonably small at the high end. Also the number of cells and strength of HOM coupling are strongly application dependent.

Low-beta applications

The high current cell shape has been scaled to a number of different beta values from 0.65 to 1 [2]. In this scaling it is important to preserve the flat outer profile of the cell that gives low tendency for multipacting. One example is shown in figure 9, using an SNS-style helium vessel and coupler for illustration.

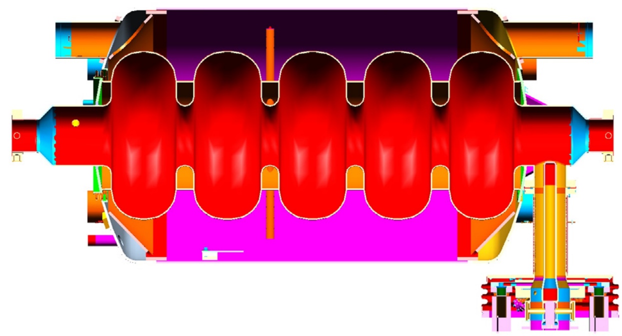

Fig. 9. High-current 650 MHz β=0.9 cavity concept

CONCLUSIONS

Although the original high-current FEL application at JLab has gone away there is still interest in this concept for other applications from high brightness electron injectors to high power CW proton drivers. The designs can be easily scaled to different frequencies and beta values and adapted to specific HOM damping requirements. A beam test of this concept would be very useful in validating the impedance characteristics, especially above the beam pipe cut-off frequency.

REFERENCES

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