

THE JLAB AMPERE-CLASS CRYOMODULE CONCEPTUAL DESIGN*

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Abstract

For the next generation of compact high-power FELs a new cryomodule is required that is capable of accelerating up to Ampere levels of beam current. Challenges include strong HOM damping, high HOM power and high fundamental-mode power (in operating scenarios without full energy recovery). For efficient use of space a high real-estate gradient is desirable and for economic operation good fundamental-mode efficiency is important. The technology must also be robust and should be based on well-proven and reliable technologies. For Ampere-class levels of beam current both halo interception and beam break-up (BBU) are important considerations. These factors tend to drive the designs to lower frequencies where the apertures are larger and the transverse impedances are lower. To achieve these goals we propose to use a compact waveguide-damped multi-cell cavity packaged in an SNS-style cryomodule.

CONCEPT

Future high-power FEL's for scientific, defense or industrial applications could benefit from a compact, economical and efficient accelerator layout. A small but powerful energy recovered linac (ERL) with a single high-current cryomodule could meet those requirements. The parameters for such a module are listed in table 1 and can be met using six strongly HOM damped multi-cell cavities, figure 1, in a stretched SNS-style cryomodule [1]. Experience with the JLab 10 kW FEL suggests that operating with less than 100% energy recovery is sometimes necessary so the linac cryomodule must be capable of supplying significant power to the beam.

Table 1: FEL Ampere-class module draft specifications.

Voltage	100-120 MV
Length	~10m
Frequency	750 MHz
Beam Aperture	>3" (76.2mm)
BBU Threshold	>1A
HOM Q's	<10 ⁴
Beam power	0-1MW

1.1 Cell shape and number of cells

There are a wide range of cell shapes in use or proposed [2]. The optimum cell shape for high beam current is a little different from the usual high gradient or low-loss shapes used for pulsed or low current machines.

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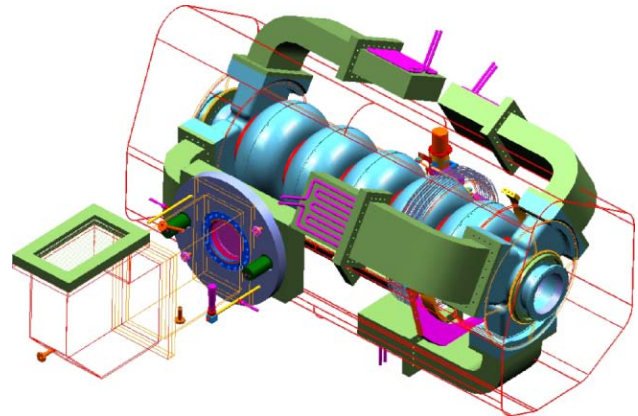


Figure 1. JLab high current cavity concept

The goal is to minimize the HOM impedances driving beam break-up instabilities (BBU) and the HOM power that must be handled by the dampers which could be very high if care is not taken in the design. Low HOM impedance suggests large irises but this works against accelerating mode shunt impedance. The frequency spectrum (and hence HOM power), is very sensitive to the outer cell shape. Using the maximum current case of all bunches filled we arrived at a shape with flat walls and a slightly elliptical equator section. This proved to be a good compromise between efficiency, HOM spectrum, surface fields and multipacting.

The number of cells is again a compromise between good HOM damping and real estate gradient [3]. Five cells per cavity should achieve the HOM damping requirements with an acceptable module average gradient.

Multipacting is very sensitive to the cell shape in the equator region but also to the overall cell parameters. Figure 2 shows the range of possible impact energies for multipacting electrons in a variety of cell shapes calculated by FishPact [4], as a function of gradient.

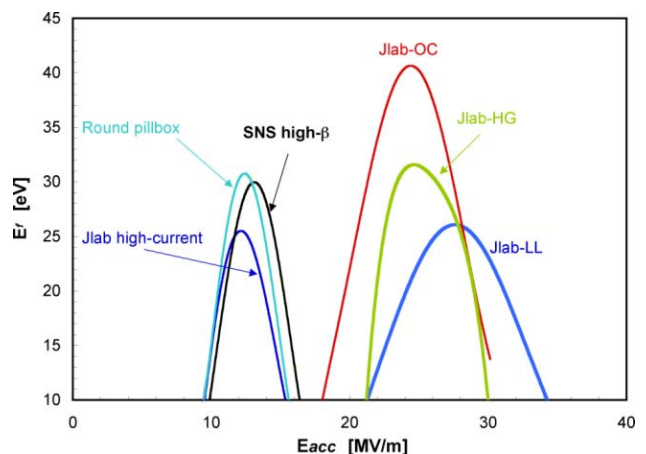


Figure 2. Impact energy vs. gradient for various shapes.

The JLab high current shape has a potential soft barrier within the operating range but the impact energies are very low so this is not expected to be a problem.

1.2 HOM damping

HOM damping is one of the most important aspects of the high-current cavity design. Scaling from the existing JLab FEL, at least two orders of magnitude improvement in transverse impedance are needed to realize an Ampere class machine. Studies show this can be achieved with good cell to cell coupling, lower number of cells (5 vs 7 in the JLab FEL upgrade cryomodule), lower frequency, and strong coupling between the end cell and the HOM dampers [3]. Given this need for strong coupling and the high power capability required we have chosen to use three waveguides on each end of the cavity with an angular offset between them, Figure 3. This configuration captures all HOMs up to a high order while not introducing any dipole asymmetry into the structure and minimizing beam line real estate used. Simulations show that this configuration can achieve the desired HOM damping and spectral distribution, figure 5, table 2.

High power waveguide HOM loads will be used with the power dissipated at room temperature. Kilowatt class HOM loads have been used in the PEP-II B-factory [5] so this is not expected to be problematic.

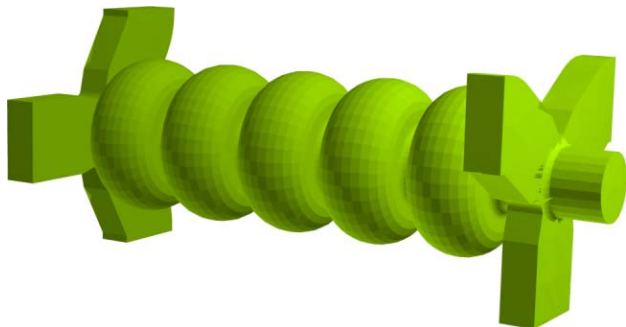


Figure 3. MAFIA model of the JLab high-current cavity.

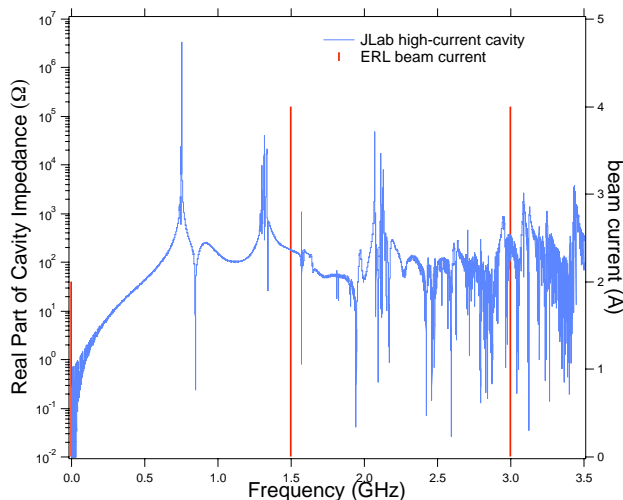


Figure 4: Monopole spectrum of high-current 5-cell cavity with strong beam harmonics at 1 Ampere current.

Table 2: Some high impedance dipole HOMs (below beam pipe cut-off frequency) for the 5-cell cavity,

Freq. (MHz)	R [†] (Ω)	Q _{ext}	Freq. (MHz)	R [†] (Ω)	Q _{ext}
925.301	3795	910	1315.389	40531	1532
958.132	12340	446	1333.229	21390	312
993.461	8372	351	1383.548	18599	3893
1056.360	26087	1494	1393.498	34520	1091
1079.92	85291	3557	1453.767	2731	7291
1093.41	51911	8367	1459.485	45786	21829

[†]R calculated at 5cm off-axis, real part of impedance.

1.3 Window and power coupler

For even 99% energy recovery the power required to be supplied by the linac RF to the circulating beam may be up to 1MW CW (167 kW per FPC), so a reliable high-power window design is essential. We have chosen to use a scaled version of the MW class waveguide window design developed for the PEP-II B-factory and tested at almost 1 MW CW at 700 MHz for LEDA [6]. A model in WR650 waveguide is also being developed to prove the concept at 1.5 GHz, see figure 5. The FPC waveguide will join one of the HOM damping waveguides at a distance from the cavity that is determined by the coupling factor.

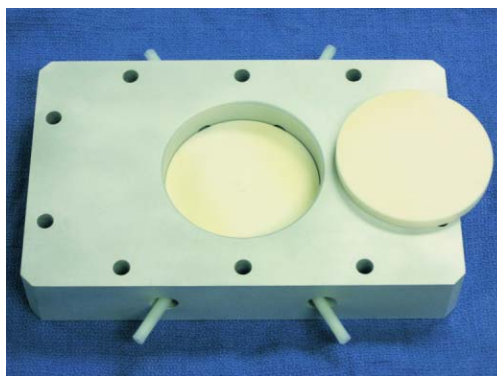


Figure 5. Test model of waveguide window in WR650.

1.5 GHz PROTOTYPES

In order to speed development initial prototyping and testing is being carried out at 1.5 GHz.

An aluminum model with one cell of the high-current shape and one waveguide end group has been made and measured, figure 6a. HOM Q's are in good agreement with simulations. A five cell aluminum model is under construction to verify the HOM Q's for the full structure.

A single cell cavity has been made out of standard fine grain niobium sheet, figure 6b, and tested. This cavity does not have waveguide end groups but was made to test the new cell shape. Peak surface fields were predicted to be slightly lower than the original CEBAF (OC) cell shape but larger than high gradient designs such as the JLab HG and TESLA shapes. There was also a concern about being able to etch and high pressure rinse the flat cell profile and whether the predicted soft multipacting barrier would be seen. In practice the cavity performed

very well with only the slight high-field Q drop typical of fine grained material and no field emission out to 32 MV/m, figure 7. A version with one waveguide end group is being fabricated, figure 8, and a five-cell model with two end groups will follow.



Fig. 6a) 1.5 GHz warm model, 6b). 1-cell niobium model.

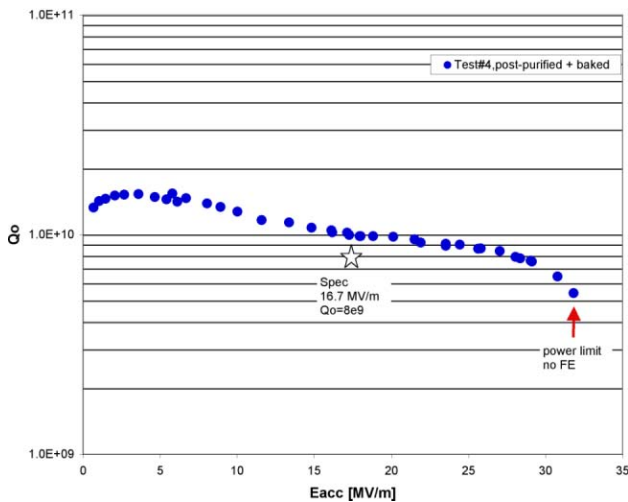


Figure 7. Q vs E for the 1.5 GHz HC single cell cavity.



Figure 8. Pressed waveguide end group before trimming.

CRYOMODULE CONCEPT

A full 3D CAD model has been developed based on a stretched and expanded SNS type space frame design, figure 9. The concept shows that six 750 MHz waveguide damped cavities can be assembled with a good packing efficiency using existing infrastructure at JLab. Table 3 lists some of the parameters of the concept cryomodule.

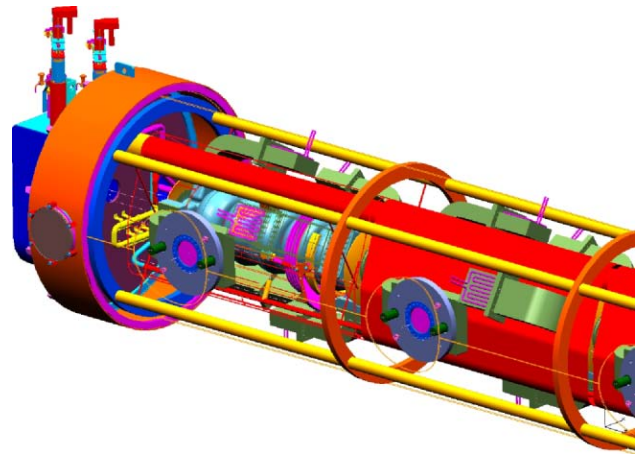


Figure 9. 750 MHz high-current cryomodule concept.

Table 3. 750 MHz cryomodule with six five-cell cavities.

Frequency	750 MHz
Cavity Length	1.4m
Iris Diameter	14 cm (5.5")
Min. Module Length	10.4m
Nominal Module Voltage	100 MV (120 MV peak)
Cavity Gradient (Eacc)	16.7 MV/m (20 MV/m max)
TE ₁₁₁ freq, Q _{ext}	958 MHz, 4.5e2 (calc.)
TM ₁₁₀ freq, Q _{ext}	1080 MHz, 3.6e3 (calc.)
TM ₀₁₁ freq, Q _{ext}	1315 MHz, 1.6e3 (calc.)
HOM Power/Cavity	~20 kW(est.)
BBU Threshold	>1A

CONCLUSIONS AND FUTURE PLANS

The JLab high-current cryomodule concept is making good progress. Initial results indicate that the strong HOM damping can be achieved and first cold cavity tests are very encouraging. In the near future we plan to complete 1.5 GHz testing of single and 5-cell cavity prototypes and then a full scale 750 MHz version. Beyond that we plan to explore opportunities for a beam test in the existing FEL.

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