The JLab Ampere-Class Cryomodule *

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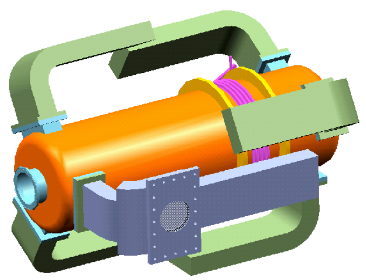
Abstract

We report on the design of a new cryomodule capable of accelerating high-current beams for future ERL based high power compact FEL's. We discuss the factors influencing the design choices, including BBU threshold, frequency, HOM power, real-estate gradient, peak surface fields, and operating efficiency. We present a conceptual design that meets the requirements of compact MW-class FEL, however this module design could be useful for a wide range of applications such as electron cooling, electron-ion colliders, industrial processing etc. The concepts developed for this design could also be useful for larger ERL-based light sources, XFELs and even linear colliders..



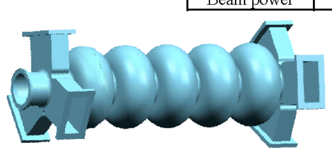
Cavity section with helium vessel, waveguide HOM dampers and waveguide window.

Introduction

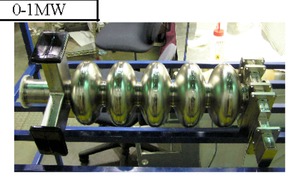
High-power FELs and other machines based on high current energy recovered linacs face issues such as beam heating of components and beam break-up (BBU) instabilities. For the next generation compact FEL being developed at JLab a new cryomodule is required that is capable of accelerating up to Ampere levels of beam current. Table 1 gives a summary of the proposed specifications for the new module. To achieve these goals we propose to use a compact waveguide-damped multi-cell cavity packaged in an SNS-style cryomodule. Challenges include extreme HOM damping, high HOM power and high fundamental-mode power (in operating scenarios where energy recovery is designed to be less than 100%).

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



Waveguide damped 1A cavity



Original CEBAF cavity

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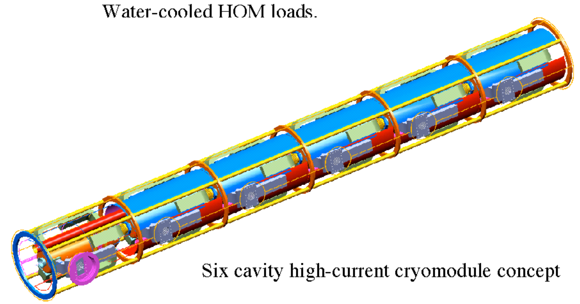
General Layout

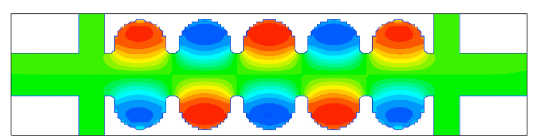
JLab space-frame design.
Six 5-cell cavities
Average performance of 16.7-20 MV/m
Actively cooled end groups.
No helium-to-beam-line vacuum flanged joints.
HOM power is taken out to ambient temperature
Water-cooled HOM loads.



Six cavity high-current cryomodule concept

Cavity shape

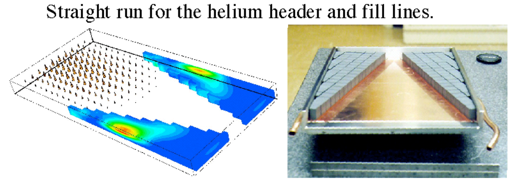
5 cells per cavity.
Rounded pillbox cell shape.
Good packing factor.
Strong HOM damping.
Healthy real-estate gradient (~10 MV/m).
HOM frequencies safely between dangerous harmonics.
Large iris diameter (140mm).



Magnetic field in 5-cell cavity after tuning end cells

HOM damping

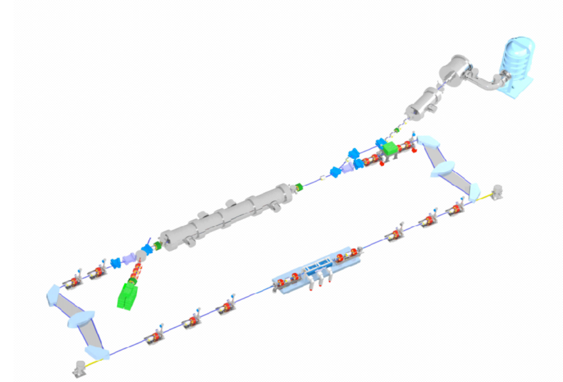
Waveguides for strong coupling.
High power handling capability.
Maximum use of active length.
Natural rejection of the fundamental mode.
Captures any orientation of dipole modes.
Captures all monopole modes even if tilted.
Waveguide end groups at opposite ends staggered.
Straight run for the helium header and fill lines.



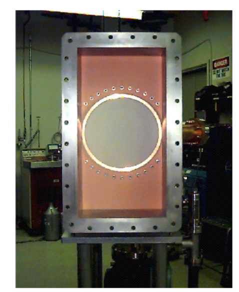
PEP-II type HOM absorber assembly

HOM load

HOM loads at ambient temperature.
Wedges of absorbing ceramic material as used on the PEP-II cavities
High-power broad-band load.
Simple fabrication steps and commercially available materials.



Compact FEL based on a single high-current cryomodule



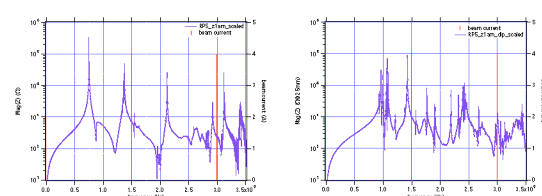
PEP-II type waveguide window assembly

Window and fundamental power coupler

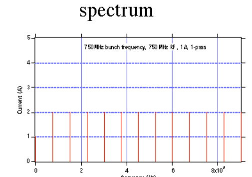
Up to 1 MW optical power.
Up to 167 kW per cavity/coupler.
Well within capacity of B-factory style windows/couplers.

Tuner

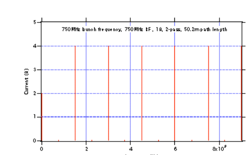
Modified 12 GeV or SNS-style tuner would work.
Investigating other alternatives.



5-cell rounded pillbox monopole and dipole spectrum

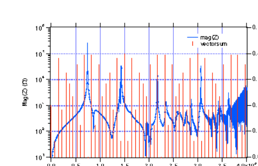


Beam spectrum for 1A, 1 pass

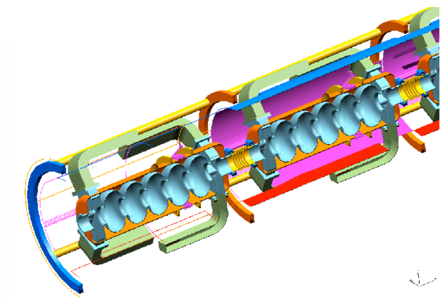


Beam spectrum for 1A energy recovered.

Beam spectrum for 100 mA, recovered



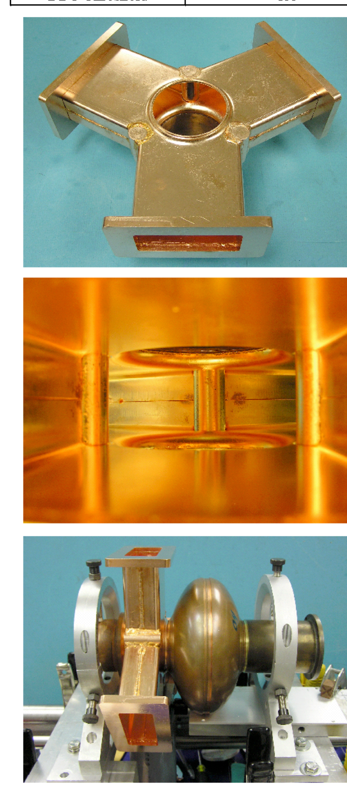
100 mA Spectrum and cavity impedance.



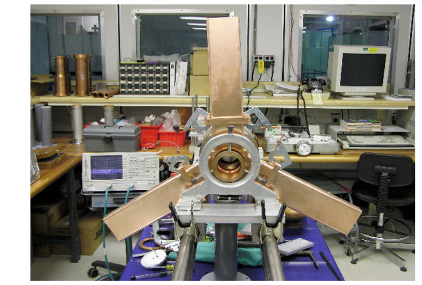
Cavity assembly in SNS-style space frame.

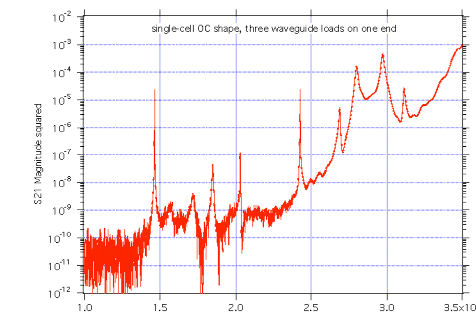
750 MHz cryomodule with six five-cell cavities with waveguide damping

Frequency	750 MHz
# cells	5
Damping Type	Waveguide
Cavity Length	1.4m
Iris Diameter	14 cm (5.5")
# Cavities	6
Min. Module Length	10.4m
Nominal Module Voltage	100 MV (120 MV peak)
Cavity Gradient (Eacc)	16.7 MV/m (20 MV/m max)
Real Estate Gradient	~10 MV/m
TE_{111} freq, Q_{ext}	947 MHz, 9.5e2
TM_{110} freq, Q_{ext}	1052 MHz, 3.3e3
TM_{011} freq, Q_{ext}	1436 MHz, 7.1e2
HOM Power/Cavity	~20 kW(est)
BBU Threshold	>1A

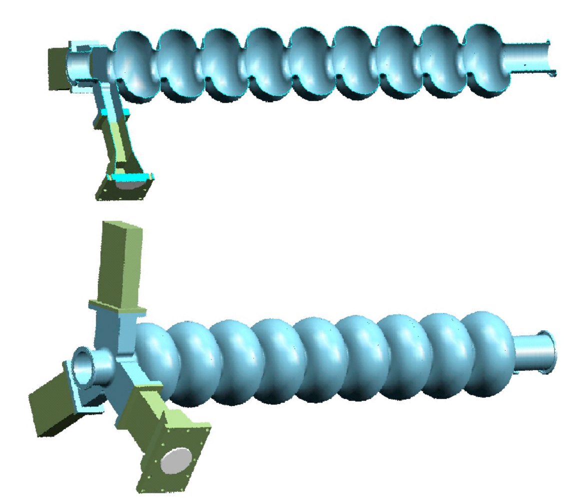


Copper model of three waveguide end group.





First measurements of copper 1.5 GHz single-cell model.



Possible ILC 9-cell version at 1.3 GHz.

To do list

Multipacting analysis of the new cell shape (under way).
Detailed thermal modeling.
Microphonic analysis.
Bellows shield.
Detailed design and prototyping of all main components.

Conclusions

Concepts in hand for the key components.

HOM damping can be achieved in a multi-cell cavity with while preserving good fundamental mode efficiency and real-estate gradient.

Concepts for the module layout and ancillary components are closely based on existing proven designs and production methods and processes in use at JLab.