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952.6 MHz SRF CAVITY DEVELOPMENT FOR JLEIC*

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Abstract

JLab is developing new SRF cavity designs at 952.6 MHz for the proposed Jefferson Lab Electron-Ion Collider (JLEIC). New cavities will be required for the ion ring, cooler ERL and booster and eventually for the electron ring to allow the highest possible bunch collision rate. The challenges include the need for strong HOM damping, high fundamental mode power couplers and high HOM power. Initial focus is on the cooler ERL five-cell cavity as this is a critical component for the strong, high energy, bunched-beam cooling concept. One-cell and five-cell Nb prototype cavities have been designed and fabricated. Details concerning the cavity fabrication and test results for the will be presented.

INTRODUCTION

Jefferson Lab is proposing a very high luminosity (~10^{34}) electron-ion collider using CEBAF as a full energy, fully polarized electron injector, new polarization-preserving figure-8 storage rings and a new ion injector complex [1]. The electron energy will range from 3 to 12 GeV with up to 3A of circulating current while up to 0.75 A of polarized protons or ions will be stored. Proton energy will range from 40 to 100 GeV in the baseline (40 GeV/u heavy ions) providing center of mass energy range from 15 to 70 GeV, extensible to higher energy by using higher field magnets in the ion ring. Continuous top-off of the electrons to maintain current and polarization is envisaged, while strong cooling of the ions will be used [2] to maintain an acceptable luminosity lifetime. The cooler will be based on a high-current Energy Recovery Linac (ERL), supplemented by a cooler circulator ring (CCR) to provide high-charge, low-emittance bunches at the full rate [3]. The ion injector complex will be quite conventional, with multiple sources to provide a wide range of ion species, and will not be discussed here.

DESIGN CHALLENGES

The high circulating currents in both rings requires careful design of all chambers and components for low impedance and good thermal stabilization. In particular all RF cavities must be designed with strong HOM damping and high power fundamental mode couplers, for example see Fig. 1. The RF systems must also tolerate beam gaps for abort kickers and injection or between trains of bunches with opposite polarization.

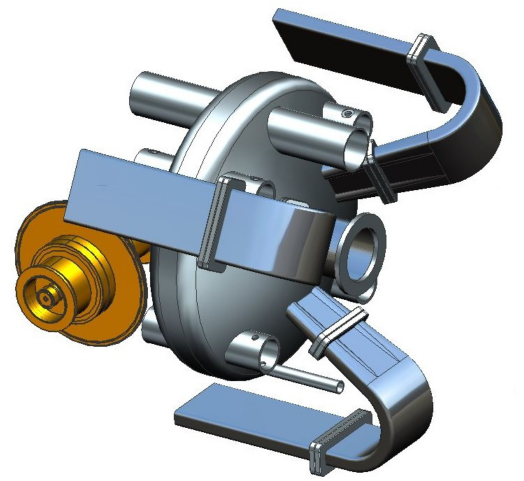

Figure 1: On-cell damper storage ring cavity concept.

In the JLEIC baseline design the electron ring will re-use the PEP-II RF systems and vacuum chambers and possibly some magnets. The frequency of the cavities will be adjusted slightly to 476.3 MHz to facilitate bunch train injection from CEBAF. This will set the maximum bunch frequency in the baseline design, however as a future luminosity upgrade these RF systems could be replaced by 952.6 MHz SRF cavities to double the number of bunches. The ion ring will also use new 952.6 MHz SRF cavities to achieve the high installed voltage needed to produce short ion bunches. The exact ion ring frequency will depend on the energy and all other RF systems must be tunable to track this frequency. Table 1 lists the main parameters for the RF systems in the JLEIC collider complex.

Table 1: High Level RF Parameters for JLEIC

	e-ring (NCRF)		i-ring	
Energy	4	10	100	GeV
Frequency	476.3	476.3	952.6	MHz
Average Current	3.00	0.684	0.75	A
Syn. Rad. Power	1.03	9.15	-	MW
E-Loss Per Turn	0.342	13.4	-	MeV
Vpeak, total	1.20	20.5	57	MV
Syn. Phase	16.5	40.6	0.0	deg
Vgap	0.301	0.790	1.19	MV
Gradient	1.0	2.5	7.55	MV/m
P-beam per cavity	257	352		kW
Cavity Wall Loss	12.9	89.1		kW
P-fwd per Cavity	432	441	64	kW
P-reflected	163	0.01	64	kW
Qext	6000	6000	5.2E4	
Cavity Number	4	26	48	cells

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STORAGE RING CAVITIES

High current storage rings such as PEP-II, KEK-B and CESR used heavily HOM-damped single-cell cavities with high-power fundamental mode couplers. For the baseline e-ring JLEIC will re-use the successful PEP-II copper cavities since they have demonstrated up to 3A operation with ~0.5 MW power per coupler [4]. The total ring current is limited to 3A or 10 MW of synchrotron radiation losses, depending on the energy. To minimize impedance only enough cavities for the energy required will be installed for each physics run.

In the ion ring the primary function of the high frequency SRF system is bunching. Higher voltage and lower fundamental power are needed, however with 0.75A circulating current strong HOM damping is still needed. For the new cavity designs several HOM damping options are considered. For a detailed discussion on HOM damping options see [5].

HOM Damping Options

SRF cavities have been shown to work well at high current using beam-pipe dampers, Fig. 2a, e.g. at KEK-B and CESR, however these are rather long and result in a low packing factor in the cryomodule. Hook type HOM couplers, Fig. 2b, are compact have been used e.g. in HERA and LEP-II but are limited to about 1 kW per coupler even with active cooling. JLab has developed beam-pipe mounted waveguide dampers, Fig. 2c, [6] that are both compact and designed for high power capability, although they do add some complexity to the cryomodule. A new HOM damping scheme is under development using on-cell waveguides, Fig. 2d. This produces extremely low HOM Q's and can handle high HOM power in a compact module. The penalty for this is a local magnetic field enhancement around the waveguide iris, Fig. 3, however this has been minimized by design to allow operation at the desired gradient. Figure 4 shows the longitudinal broad-band HOM spectra of these options. Clearly the on-cell damper version produces the best result. The transverse spectrum follows a similar trend. Depending on the ion ring voltage requirements a 2-cell cavity may be beneficial. The on-cell waveguide damper concept was first used successfully on an SRF cavity for the ANL short pulse X-ray (SPX) prototype [7].

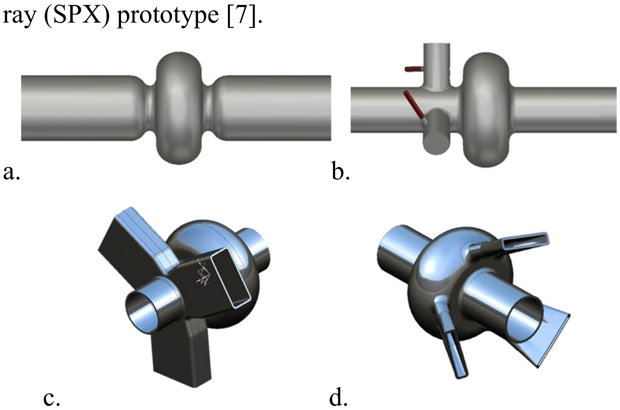

Figure 2: a) enlarged beam pipes, b) three coax dampers, c) three waveguides, d) three on-cell dampers.

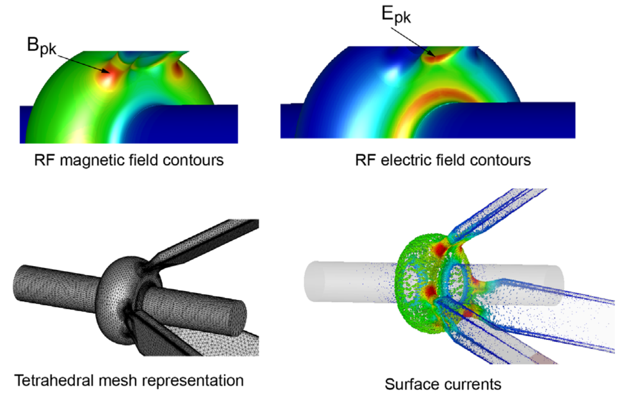

Figure 3: Field enhancements around on-cell dampers.

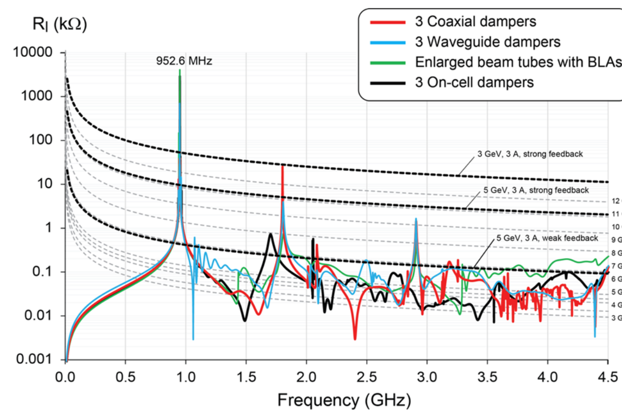

Figure 4: Longitudinal broad-band HOM spectrum of different damping schemes applied to a single-cell SRF cavity and e-ring BBU threshold at different energies [5].

HIGH-ENERGY COOLER

The cooler, Fig. 5, consists of a high current ERL and injector combined with a circulator ring. The injector must produce magnetized bunches up to 3.2 nC, but the 11-turn CCR relaxes the current requirement in the ERL by the same factor to 138 mA. The ERL linac will use five-cell SRF cavities with the same high-current cell profile as the storage ring cavity. Either conventional hook-type or end group waveguide type HOM dampers, Fig. 6a, b, may be used, depending on the details of the beam spectrum. This is currently under investigation. The injector, which is not energy recovered, will need to use one- or two-cell cavities with high power couplers similar to the storage ring design. A low frequency buncher cavity may be needed after the gun to handle the strong space charge forces in the high intensity bunch [8]. The bunches are kicked in and out of the CCR by newly designed normal conducting five-mode harmonic kickers [9].

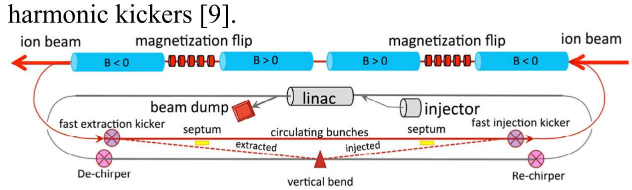

Figure 5: High energy electron cooler baseline design.

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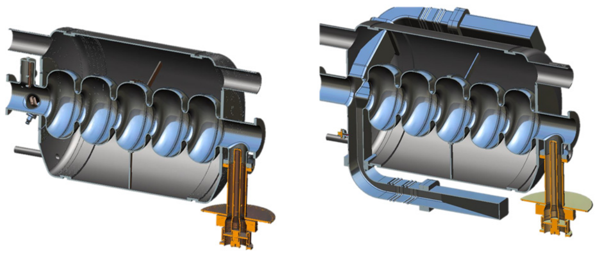

a. b.

Figure 6: Five cell cooler ERL cavity with a) three hook couplers, b) three waveguide HOM dampers.

CRAB CAVITIES

The interaction region includes a 50 mrad crossing angle so crab cavities are needed to maintain luminosity. The crab system could be any harmonic of the bunch frequency, but 952.6 MHz turns out to be a good choice balancing beam pipe aperture with wavelength and the number of cells.

The crab cavities are being developed by Old Dominion University (ODU), [10]. Table 2 shows the major parameters. The crab cavities must also be high-current devices with strong HOM damping and high power HOM absorbers.

Table 2: Crab Cavity System High Level Parameters

Parameter	Unit	Electron	Proton
Energy	GeV	10	100
Bunch frequency	MHz	952.6	
Crossing angle	mrad	50	
Betatron function @ IP	cm	10	
Betatron function @ crab cavity	m	~200	363.44
Integrated kick voltage per IP side	MV	~2.8	20.82
Number of cavities per IP side		3	18
Number of cavities total		6	36

CAVITY R&D

The first single-cell 952.6 MHz cavity is complete, Fig. 7, and it is undergoing qualification testing. The first preliminary result before low-temperature baking is shown in Fig. 8. The gradient is good and we expect both the Qo and the gradient to be improved after the low-temperature baking. Cable heating limited this test before the quench limit was reached. A five-cell cavity is presently in fabrication.

The fabrication processes for the hook-type HOM damper and waveguide end groups are well established at JLab, however the new on-cell damper concept needs to be developed. Fig. 9 shows one possible forming method, by deep drawing the iris out of the cell with special tooling. Initial simulations using ANSYS™ indicate that this should be possible. Welding in separately fabricated parts would be another low risk option. In either case the welds must be safely away from the peak magnetic field region just at the edge of the iris.

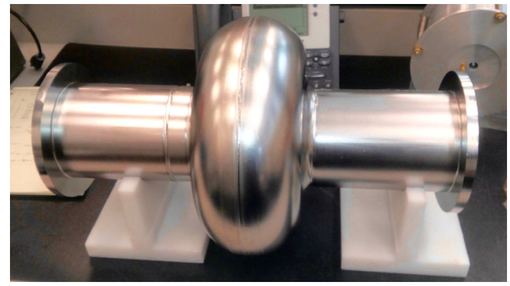

Figure 7: First 952.6 MHz cavity at JLab.

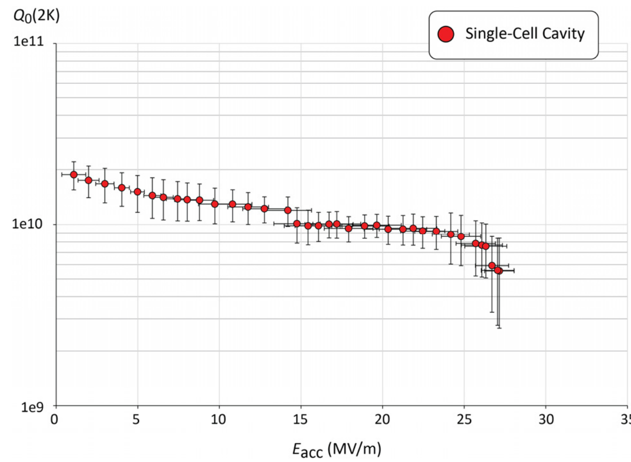

Figure 8: Preliminary Result of 952.6 MHz 1-cell cavity.

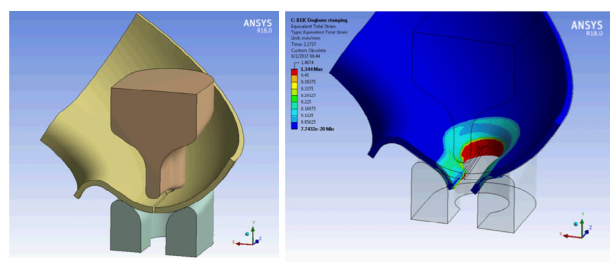

Figure 9: Simulation of on-cell damper iris formation.

CONCLUSION

JLEIC has a number of challenging SRF cavity needs. The various 952.6 MHz cavity designs are well advanced and the first prototype cavity test is encouraging. HOM damping schemes are being refined to meet the differing demands of the high current storage rings, cooler ERL and injector. A new on-cell waveguide scheme may improve HOM damping significantly. The RFD type crab cavity being developed by ODU is well suited to this application. A modular approach to cavity and cryostat design is being followed to reduce costs and development time. These concepts may be useful for other projects.

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