SUPERCONDUCTING RF SYSTEMS FOR eRHIC*

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Abstract

The proposed electron-hadron collider eRHIC will consist of a six-pass 30-GeV electron Energy Recovery Linac (ERL) and one of RHIC storage rings operating with energy up to 250 GeV. The collider design extensively utilizes superconducting RF (SRF) technology in both electron and hadron parts. This paper describes various SRF systems, their requirements and parameters.

INTRODUCTION

In the proposed collider eRHIC [1] hadrons from one of the RHIC storage rings will interact with electrons accelerated in a six-pass ERL. The maximum energy of protons will be 250 GeV and the maximum energy of electrons will be 5 GeV during Phase I with further upgrade to 30 GeV. The machine will heavily rely on SRF technology for production and acceleration of electrons, cooling of hadron beams and realizing crab crossing collision scheme. Figure 1 presents a layout of the collider with locations of various SRF systems in the existing RHIC tunnel. The injection system consists of a 10 MeV linac and 600-MeV single-pass ERL. Two 2.45 GeV SRF linacs in combination with six passes make main ERL. In addition to main SRF linacs, it will have an energy loss and energy spread compensation linacs. The coherent electron cooling (CeC) accelerator will consist of a low frequency SRF gun and buncher and a 136 MeV ERL. Finally, there will be SRF crab cavities for both hadrons and electrons. In this paper we describe SRF systems of eRHIC, present their parameters and preliminary design considerations.

704-MHz SRF LINACS

SRF linacs for three ERLs (main ERL, 600-MeV pre-accelerator, and CeC) will utilize the same 704-MHz linac technology with minor modifications. Some parameters of these linacs are presented in Table 1. Two main ERL linacs will be located in the IP2 and IP10 straight sections, where their lengths are limited to 200 m for each linac. Parameters of the main linacs are listed in Table 2. The energy of the main ERL will be increased from 5 GeV in Phase I to 30 GeV in stages by adding cryounits to the main linacs until they occupy all allotted space. Due to synchrotron radiation power loss at high energies, the beam current will be lowered at energies above 20 GeV to keep the power loss below 10 MW.

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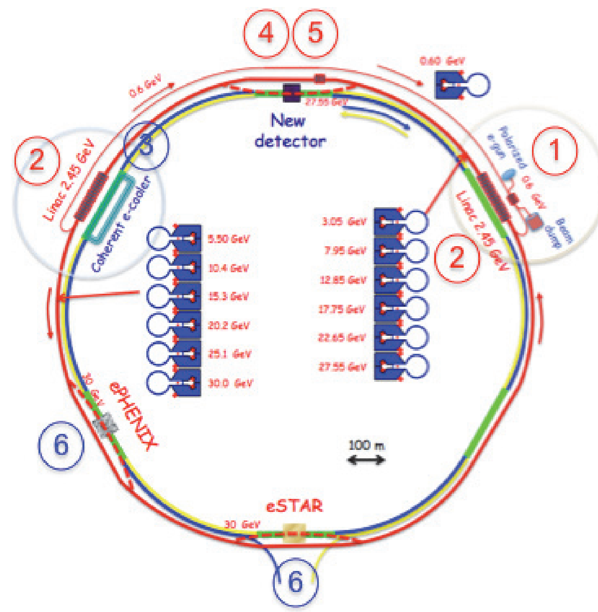

Figure 1: Layout of eRHIC showing locations of SRF systems in the existing RHIC tunnel: 1 – main ERL injection system; 2 – two main SRF linacs; 3 – coherent electron cooling of hadrons; 4 – SRF linac for energy loss compensation; 5 – harmonic SRF linac for energy spread compensation; 6 – SRF crab cavities for hadrons and electrons in IP regions.

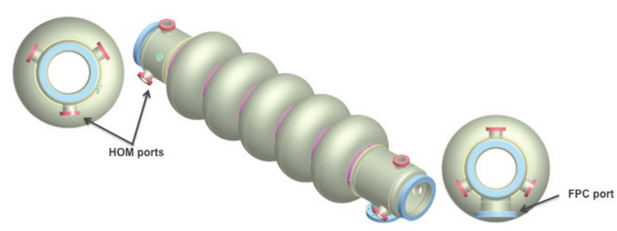

Figure 2: Five-cell SRF cavity for eRHIC.

A five-cell 703.8-MHz superconducting cavity for high-current applications is under development at BNL [2-4]. The cavity (Figure 2) has an optimized shape that supports strong damping of higher order modes (HOMs), which is accomplished via six antenna-type couplers attached to the large diameter beam pipes. Each cavity will be housed in an individual cryounit (Figure 3). A series of such cryounits will form one long cryomodule with 1-meter long transitions to room temperature at the ends.

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Table 1: Parameters of the 704-MHz SRF Linacs

Parameter	Main linac	Pre-accelerator ERL	CeC ERL	10-MeV injector linac
Energy gain [MeV]	2450	590	136	10
Beam current [mA]	50	50	70	50
Linac length [m]	200	60	19	5.2
No. of cavities	120	30	8	2
E_{acc} [MV/m]	19.2	18.5	15.1	4.7

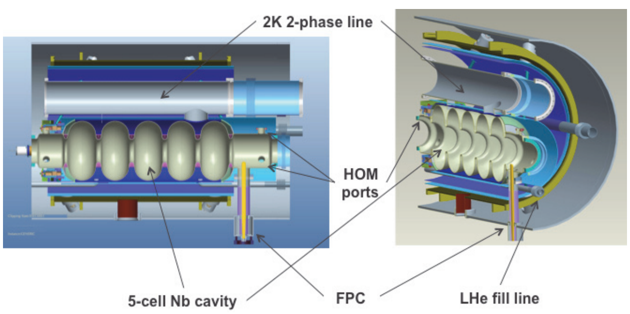

Figure 3: Preliminary layout of a cryounit for eRHIC.

Table 2: Parameters of the Main ERL Linacs

Energy gain per linac at 30 GeV	2.45 GeV
Beam current per pass (E ≤ 20 GeV)	50 mA
Bunch frequency	14.1 MHz
Bunch length	2 mm rms
RF frequency	703.8 MHz
Linac length	200 m
No. of cavities per linac	120
Filling factor	0.64
Cavity type	Elliptical, 5-cell
E_{acc} at 30 (20) GeV	19.2 (12.7) MV/m
Peak detuning due to microphonics	6 Hz
RF power per cavity	10 kW
Cavity loss factor	3.5 V/pC
Cavity Q_0	4×10^{10}
Operating temperature	1.9 K

ENERGY LOSS AND SPREAD COMPENSATION LINACS

To compensate significant energy losses of electrons due to synchrotron radiation, higher order modes, and resistive walls, it was decided to use a dedicated SRF linac. The linac will operate at the second harmonic of main RF, 1408 MHz. It will be located in IP12 and will accelerate electrons only on the high-energy pass. The cavities will be two cells elliptical structures with two fundamental power couplers (FPCs), thus looking similar to the 1300 MHz Cornell ERL injector cavities [5]. Some parameters of the energy loss compensation linac are listed in Table 3. As the main limitation at 20 GeV comes from RF power (set to 100 kW per FPC), they will operate at relatively low gradient of 9.4 MV/m. Accelerating gradient at 30 GeV will reach 18.3 MV/m.

Interaction of short electron bunches with surrounding structures will induce significant energy spread [6]. Several schemes of compensating this effect are under consideration. One of them is to use a harmonic (third or fifth of main RF) SRF linac. If this option is chosen, the linac will be located in IP12.

Table 3: Parameters of the Energy Loss Compensation Linac

Parameter	at 20 GeV	at 30 GeV
Energy gain [MeV]	98	389
Beam current [mA]	50	12.6
Linac length [m]	21	43
No. of cavities	49	100
E_{acc} [MV/m]	9.4	18.3
Beam power per cavity [kW]	200	98

LOW FREQUENCY SRF STRUCTURES

Low frequency SRF structures will be used at the initial stages of acceleration/bunching in the 10 MeV main ERL injector and in the CeC injector.

3.5-nC bunches of polarized electrons for main ERL will be produced by a "Gatling gun" [7, 8]. The bunches will be relatively long to alleviate space charge effects and will have to be shortened prior to injection into the 704 MHz SRF linac. This will be accomplished by velocity modulation in a 112 MHz quarter wave SRF buncher. A third harmonic single-cell elliptical SRF structure will be used for linearization. The buncher will operate at accelerating voltage of 1.3 MV and the third harmonica cavity – at 0.6 MV.

An efficient cooling of high-energy hadrons will be accomplished by using coherent electron cooling technique [9]. High-charge (5 nC) non-polarized electron bunches will be generated by a 112 MHz quarter wave

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Table 4: Parameters of the eRHIC Crab Cavities

Parameter	225 MHz	450 MHz	676 MHz	1013 MHz
Kick voltage per cavity [MV]	4.13	1.86	0.762	0.95
Cavity type	QWR	QWR	QWR	elliptical
No. of cavities per IP	12	6	2	4
R_t/Q [Ohm]	291	291	291	46.7
Q_0 (at T [K])	$>10^9$ (4.5 K)	$>10^9$ (4.5 K)	$>10^9$ (4.5 K)	$>2.2\times10^{10}$ (1.9 K)

SRF gun [10] operating at 2 MV. Two third harmonic single-cell elliptical SRF cavities will operate at 5 MV each and provide bunching and further acceleration prior to injection into the CeC ERL.

CRAB CAVITIES

A crab-crossing scheme will be utilized in the eRHIC interaction region, where particle trajectories intersect at 10 mrad crossing angle. The crab-crossing system for hadrons includes 225 MHz main crab cavities and second and third harmonic cavities to linearize the transverse kick along the hadron bunches [11]. The main cavity design is based on a quarter wave (QW) coaxial resonator. The QW shape provides a very compact design, absence of lower and same order modes, and large separation of the fundamental and first higher order mode. The harmonic crab cavities will be of a similar design. Crab cavities for electrons will operate at higher frequency, 1013 MHz, as the electron bunches are very short. Selected parameters of eRHIC crab cavities are presented in Table 4.

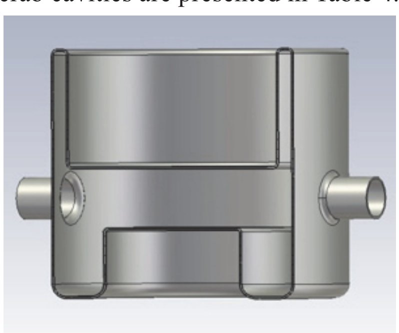

Figure 4: Concept model of QW crab cavity [12].

SUMMARY

The future electron-hadron collider eRHIC will rely on several superconducting RF systems to reach its high luminosity goals. Five-cell, 704 MHz elliptical structures will be used throughout the machine to accelerate electrons in the main ERL, its injector and in the coherent electron cooling accelerator. The cavities will have to accommodate high average beam currents and will have to be strongly HOM-damped. The optimized cavity shape has been developed and design of HOM coupling scheme is in progress at BNL.

During initial stages of acceleration, when electron bunches are still relatively long, low frequency SRF structures will be utilized: 112 MHz SRF gun for CeC, 112 MHz quarter wave bunchers, and 336 MHz single-cell elliptical bunchers. A prototype SRF gun cavity has been fabricated and tested. Fabrication of its cryomodule is in progress.

QW SRF cavities will be used in the crab-crossing scheme at the IPs. The novel design offers compactness and good HOM properties. Similar design, proposed for the LHC upgrade, is under active development [13, 14].

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