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RUNNING CESR AT HIGH LUMINOSITY AND BEAM CURRENT WITH SUPERCONDUCTING RF SYSTEM*

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Abstract

The transition from normal conducting to superconducting RF system has been completed at CESR in 1999. The new system is one of the changes, which allowed the collider to operate at higher currents and reach higher peak luminosity. The commissioning results and operating experience with the SRF system are presented alongside with describing its effect on CESR performance. Future plans are discussed.

1 INTRODUCTION

The Cornell Electron Storage Ring (CESR), a *e+e-* collider operating on and near the Υ(4S) resonance (E ≈ 5.3 GeV), is the only single-ring symmetric B-factory in the world. CESR has achieved a peak luminosity of 8.3×10^{32} cm^{-2}s^{-1}, a total beam current of 650 mA and a beam-beam tune shift parameter ξv = 0.05. At present each beam consists of 9 bunch trains, each is populated with 4 bunches spaced by 14 ns, but the machine optics allows increase of number of bunches per train to 6.

CESR is nearing completion of a Phase III of its luminosity upgrade [1] which includes upgrading RF system from four 5-cell normal conducting cavities to four single-cell superconducting niobium cavities. This, together with installation of new interaction region (IR) optics, will lead to the total current increase up to 1 ampere and luminosity up to 2.2×10^{33} cm^{-2}s^{-1}. The RF system upgrade was successfully completed and new system is in operation. The high-gradient capability of the SRF cavities will allow reduction of bunch length from 19 mm to 13 mm. RF power delivered by each cavity will be 325 kW at 1 A beam current.

2 RF SYSTEM DESCRIPTION

The superconducting RF system [2] consists of two RF stations (East and West). Each station includes two 600 kW YK1300 Phillips klystrons, two single-cell superconducting niobium cavities in their individual cryostats (termed cryomodules), and a station cryogen distribution valve box. WR1800 waveguide can be arranged to feed two cavities (E1 and E2 in the East or W1 and W2 in the West) from one klystron via magic T RF power splitter or to feed each cavity from its own klystron. In addition, a processing area (PA) can accommodate one cryomodule or RF window assembly for high power testing and conditioning. One of the West klystrons can be connected to the PA test set up.

Liquid helium is provided by two 600 W refrigerators supplying 2000 liter storage dewar. Rigid transfer lines transport liquid helium, cold gaseous He, and liquid nitrogen between the refrigerator and storage dewar to a centrally located main distribution valve box. From the main valve box, rigid transfer lines lead to satellite valve boxes or directly to the superconducting elements.

3 COMMISSIONING RESULTS AND OPERATION

The RF system replacement began in September 1997 and was performed in stages, with installation of SRF cryomodules one at a time in place of old normal conducting cavities.

During commissioning phase of the first (E2) cavity installation, CESR beam currents were limited by travelling wave power (forward power minus reflected power) which could be tolerated by the cavity input coupler. We observed vacuum trips at rather repeatable power levels due to gas evolution brought on by multipacting in the window and coupler region. Two processing techniques have proven to be useful in raising the travelling wave power limits: high RF power pulse processing and beam processing. Detail description of them can be found elsewhere [3].

A second variety of vacuum trips arose from RF heating of the waveguide thermal transition section. Such vacuum events showed a measurable temperature rise on the transition section, and were accompanied by a large release of hydrogen as observed on an RGA. Cryosorbed hydrogen was released as the surface was heated. After warming up the cavity to room temperature and baking the window *in situ* to 110°C

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during scheduled CESR shutdown, the beam power delivered began to rise steadily and reached 180 kW. After about 2 months in operation, the ability of the cavity to deliver RF power began to deteriorate again due to the fast vacuum trips. After another warm up the E2 power delivered to beam eventually reached 212 kW. Experience with the first SRF cavity suggested modification to the cryomodule design and handling procedures, which were incorporated into subsequent installations.

When the second (E1) cryomodule was tested at high power in the processing area, the cavity quenched at gradient around 5 MV/m, below the 6 MV/m acceptance threshold and significantly below 11 MV/m reached in a vertical test. Since disassembly and re-assembly of the cryomodule to re-etch the cavity is a several month long procedure, we performed a risky operation of using a long stick to wipe the cavity equator bottom *in situ* [4]. Apparently, a stainless sliver from a sheared tongue and groove seal migrated to the cavity bottom and partially melted during high power RF testing. Fortunately, the melted stainless steel did not wet well to the niobium, and after removal, cavity performance improved considerably, exceeding the 6 MV/m acceptance threshold. The second cavity was installed in October 1998 and reached 218 kW within one month of operation.

The third (W1) cavity was installed in March 1999. A short 6-week running period in April-May 1999 was devoted to commissioning of the new SRF cavity, exploring beam current limits and running beams for CHESS (Cornell High-Energy Synchrotron Source) experimental users. At first, the vacuum waveguide arcs discussed above limited the power, delivered to the beam by this cavity. The cavity was warmed up to 50 K to remove absorbed hydrogen. Following this warm up and subsequent high-power pulsed processing the beam power delivered through W1 increased from 140 kW to 260 kW.

The last cavity (W2) was installed in September 1999. This cavity has thermal breakdown at 7.8 MV/m due to Nb material defect. It was easy to process this cryomodule, but after about one month of running we began to get frequent RF trips due to vacuum bursts in the cavity. The problem was traced to a vacuum leak on a wire seal. Partial warm ups to 60 K every month of operation allowed us to reduce the frequency of vacuum trips and run the machine until scheduled down in February 2000. During down period we installed vacuum dam around the leaky seal. This temporary cure allows us to keep the cryomodule in CESR until spare cryomodule is ready.

SRF cavities have operated in the range of 5 to 7 MV/m with average accelerating gradient at present of 5.6 MV/m (total voltage of 6.7 MV). This is not limited by the performance of cavities, but by operation reasons: with present lattice design it is easier to tune CESR to high peak luminosity with lower synchrotron frequency. The maximum power delivered to date by SRF cavities is 260 kW (W1), 225 kW (E1), 220 kW (E2), and 212 kW (W1). Figure 1 illustrates CESR peak beam current increase with installation of SRF cavities.

Since early 1996 CESR beam currents have begun to be limited by a longitudinal coupled bunch instability due to high Q factor of parasitic modes in normal conducting RF cavities. A staged replacement of the normal conducting RF allowed us to study the impact on longitudinal threshold instability at each step [5,1]. The increase of instability threshold with installation of SRF cavities is not as quite dramatic as we might have expected. A detailed calculation and comparison to threshold data has been performed. The analysis showed good agreement between calculations and measurements for the case of four normal conducting RF (NRF) cavities and three NRF plus one SRF, but began to worsen for the two NRF plus two SRF case. These results suggest that as NRF cavities are removed, the impedance of the rest of the ring becomes more important and dominates the longitudinal dynamics when all NRF cavities are removed. Recent studies of electrostatic separators [6] show that their higher-order mode (HOM) impedance is rather high and can explain lower than expected longitudinal instability threshold. We must note though that if before the SRF system installation longitudinal instability usually caused beam dump, now instability is self-limiting and does not cause beam loss. A digital multi-bunch longitudinal feedback system has been developed to damp the excited longitudinal motion [7]. With the longitudinal feedback system in operation, we have been already able to operate at beam currents a factor of 2.3 above the instability threshold, and it will provide enough stability margin to operate with 1 A beam current in CESR.

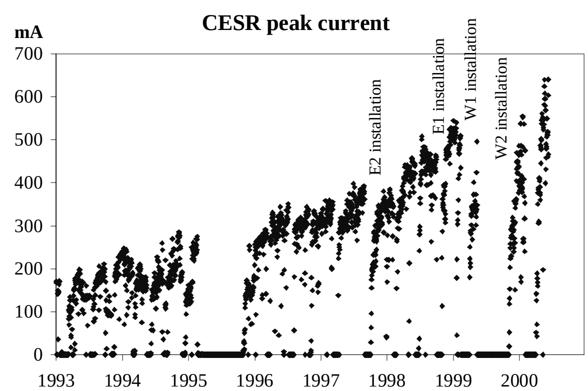

Figure 1: CESR peak current increase with installation of SRF cavities.

5 FUTURE PLANS

Installation of two superconducting quadrupole lenses in the interaction region (IR) will allow CESR to operate with small β^* [1]. To take advantage of this IR optics improvement we have to shorten the bunch length to be about equal to β^*. With the existing 9 bunch train optics, momentum compaction α = 0.0112. A total accelerating voltage of 22 MV yields a bunch length of 10.5 mm at 9.3 mA/bunch. We are planning to install two additional SRF cavities in the IR region. Total voltage of 22 MV corresponds to an average accelerating gradient of 12 MV/m. This should give us ability to tune machine to higher peak luminosity (see Table 1).

Table 1: CESR parameters for Phase III upgrade

Parameter	PhaseII	Phase III		
		A	B	C
No. of cavities	4	4	4	6
Acc. gradient [MV/m]	5	5	10	12
Accel. voltage [MV]	6	6	12	22
Bunch length (zero current) [mm]	18.1	18.1	12.8	9.5
Bunch length (@9.3 mA) [mm]	19.5	19.5	13.8	10.5
β^* [mm]	18	18	13	10
No. of bunches/train	4	6	6	6
Peak current [A]	0.54	1	1	1
Current/bunch [mA]	7.5	9.3	9.3	9.3
Loss factor [V/pC]	6	6	8	13.2
Beam power [MW]	0.7	1.3	1.35	1.5
Transmitted power/cavity [kW]	175	325	337	250
Vertical tune shift param.	0.05	0.05	0.05	0.06
Luminosity [$\times 10^{33}$ cm^{-2}s^{-1}]	0.83	1.6	2.2	3.5

In order to reach high gradient of 12 MV/m we will have to improve performance of our RF system. E1 cryomodule has to be taken out of the ring, opened and cavity repaired. W1 cryomodule has to be taken apart to replace the cavity and fix leaky seal. Our cryostats can tolerate dynamic heat load up to 200 W per cryostat. This means that at 12 MV/m cavity quality factor should be $\geq 10^9$. To reach this value we are going to exploit cavity baking technique. Experiments at several laboratories showed that after baking cavity in vacuum at temperatures of 80°C to 150°C, its Q factor increases by a factor of 2. We baked our spare cavity at 140°C for 48 hours and obtained similar result (Figure 2.)

One can see from Table that beam power delivered by each cavity will drop from 337 to 250 kW when we add two more cavities to the system. This means that with fixed coupling cavity is not matched any more to the waveguide at 1 A beam current, and there will be significant amount of reflected power from each RF coupler. Thus efficiency of the RF system will not be good. Therefore we can not easily change cavity coupler, we are going to use a high RF power waveguide transformer similar to proposed in [8] and successfully used at DESY laboratory. The use of transformer will allow us to reach matching conditions at 1 A.

Addition of two cavities will require upgrade of cryogenic system and RF transmitters. One more 600 W refrigerator will be added to two others, which are in operation already. Also, we consider possibility of running cryomodules at temperature lower than 4.5 K. Slight modification of the cryostat design is necessary to fit in very tight space available in the IR region.

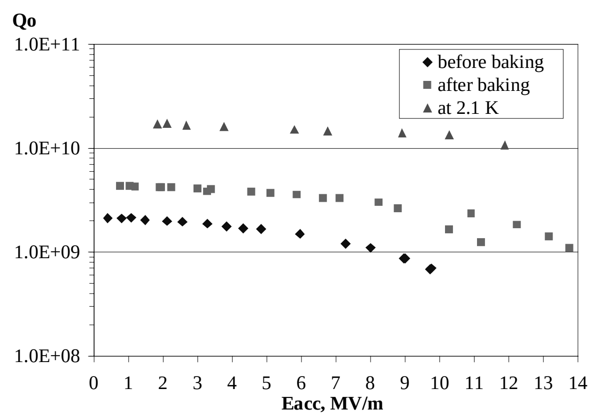

Figure 2. Q vs. Eacc plot for spare cavity tested before and after 140°C, 48 hr bake.

6 CONCLUSIONS

Cornell design of a superconducting HOM damped RF cavity cryomodule for high-current electron storage ring proved to be successful. Installation of new SRF cavities in CESR already helped to increase total beam current to 650 mA and peak luminosity to 8.3×10^{32} cm^{-2}s^{-1}. In the near future we should be able to reach CESR Phase III design beam current and peak luminosity. Based on our successful operating experience we plan to upgrade our SRF system by adding two more cryomodules and increasing accelerating gradient to 12 MV/m. This will help us to shorten the bunch length and as result to reach peak luminosity as high as 3.5×10^{33} cm^{-2}s^{-1}, taking full advantage of focusing strength of new superconducting IR quadrupole lenses.

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