Superconducting RF Activities at Cornell University*◊

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CESR LUMINOSITY UPGRADE

The decision was made to try to increase the luminosity of CESR as high as possible with a single magnet ring. This, the Phase-III plan, can yield a luminosity of 1 x 10^{33} with 45 bunches in each beam for a total current in each beam of 0.5 amperes. This plan utilizes four superconducting, single cell cavities. The required gradient, E_{acc}, in each cavity would be 6 MV/m for a peak total accelerating voltage of 1.8 MV and the power transferred to the beam in each cavity would be 325 kWatts.

The use of only four SC accelerating cells as compared to the present twenty normal conducting cells decreases both the broad band and narrow band impedances (with adequate damping) sufficiently to allow stable operation at these half ampere current levels.

BEAM TEST RESULTS

As part of the plan to design, manufacture and test the required SC RF cavities, a series of tests in the horizontal cryostat were performed with the B Cell cavity. A sketch of the completed Cavity-cryostat system is shown in Figure 1.

The last test, performed in August 1994, was made with the cavity installed in the CESR ring, west of the CLEO detector. The refrigerator system consisted of two existing refrigerator units, nominally rated at 100 watts each, feeding into a 1000 liter dewar. The cold gas from the cavity cryostat was returned to the refrigerator.

Most of the beam tests were conducted at 5.3 GeV, for which the total voltage required was 7-7.5 MV. Through most of the tests, the CESR NRF system of four 5-cell copper cavities provided 6 MV (gradient = 1 MV/m) and the SRF cavity provided about 1.5 MV.

High Current Operation

The maximum current for the test was 220 mA (in 27 bunches). The current limit was set not by the performance of the cavity but by the heating (80-100C) of CESR components, in particular a sliding joint of the CLEO beam pipe. Immediately following the multibunch 220 mA run, we stored a maximum of 44 mA in a single bunch. Note that the quantity: (number of bunches) x (single bunch current)^2 was nearly the same (actually 8% higher) as the 220 mA, 27 bunch run.

The cavity was kept in CESR for 7 days, during which beam was run through the cavity for a total period of approximately 65 hours. For most of this time the operating conditions were at a beam energy of 5.3 GeV and a beam current of 100 mA.

There was no observable increase in total cryogenic loss (80 watt) as a function of beam current. There was an increase in heat load, from 50 to 80 watt, when the RF was turned on. The ambient losses due to the static cryostat heat leak (25 watt) and the transfer lines was (25 watt) were measured independently to give a total of 50 watt.

Higher Gradient Operation

At 5.0 MV/m ($Q_0 = 10^9$) the cavity was run with stability for 1/2 hour at 100 - 110 mA beam current. Between 5 and 6 MV/m the total heat load increased because of field emission to 150 watt at 6 MV/m, the highest load that the refrigeration system could handle. Our ability to process away field emission to reach gradients higher than 6 MV/m was limited by the performance of the high power window (as discussed below).

Due to higher heat loads above 5 MV/m, it was only possible to run the cavity for short periods. Nevertheless we ran the cavity with beam currents between 95 and 120 mA and cavity gradient up to 6 MV/m.

Delivering Beam Power

The maximum power delivered to the beam was 155 kW, a factor of 2 above the world record of the SRF cavity tested in TAR at 2 MV/m. For the CESR/SRF high beam power test, the relative phasing between the NRF and SRF was adjusted so that the bunches went through the SRF cavity at the peak of the RF voltage. The NRF cavities were run at the synchronous phase, provided beam stability and extracted the excess power delivered to the beam.

Other tests

The performance of the HOM loads, the interaction of ferrite HOM loads with the beam, and beam stability studies were all as expected and have been reported elsewhere. Briefly,

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◊ Unabridged PS version of this paper available at URL http://w4.lns.cornell.edu/public/SRF/1995/SRF 950908-13/
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we confirmed that the loads will tolerate the power expected for a one amp in CESR-III and that there would be no instabilities due to the narrow band and broad band impedances of the SRF cavity system with ferrite HOM loads.

After choosing a new optics at 4.3 GeV, the SRF cavity was operated without NRF. The maximum beam current stored was 29 mA in 9 bunches, limited by injection into the unconventional optics. There was no evidence of instability and all regulation systems (tuner, RF amplitude, phase, bath pressure etc.) worked well. A maximum 57 mA, 9 bunch electron beam was stored at 5.3 GeV. 100 watt of synchrotron radiation power incident on the stainless steel taper increased the temperature to 100 C and degraded the vacuum in this region from $6x10^{-9}$ to 6×10^{-8} torr. The cavity operated with stability in the presence of this large SR dose and there was no increase in cryogenic losses.

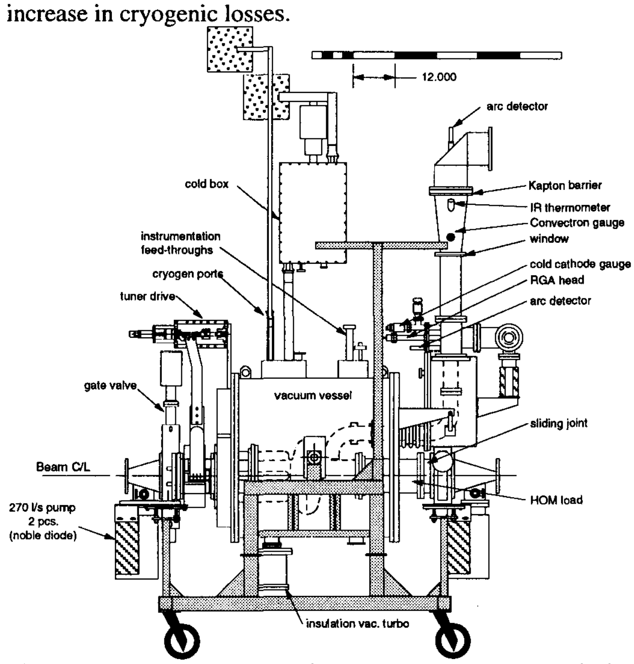

Figure 1: Layout of the cavity-cryostat system used during the CESR high current beam test of the SC B Cell cavity

SYSTEM DESCRIPTION

By the summer of 1996, the first of the final B Cell cavities will be installed in CESR. This will be used in addition to the four NRF cavities until such time that this new system has shown sufficient reliability and that the additional three cavities are ready for installation. The NRF cavities would be removed at that time. In the meantime the resources of the SRF group are being utilized in the specification, procurement and testing of all the required components. These include the niobium cavities, the cryostats, the RF windows, the HOM loads, and the refrigerator and cryogen distribution system. In addition to these items there are also the usual control, data logging, and monitoring requirements as well as the required changes to the transmitters and waveguide presently being used on the NRF system.

By the spring of 1996, we plan to have the Mk 2 cavity and cryostat assembled and tested, off line, at high power in conjunction with the new refrigerator system. This will allow the operational debugging of the many new systems without interfering with the normal, High Energy Physics, operation of CESR.

CAVITY PROCUREMENT

The 500 MHz cavity used in the beam test was manufactured by Dornier and has been previously described. This cavity performed satisfactorily in all respects but during one of the latter chemical treatments it is thought that the acid temperature was allowed to rise and consequently the cavity has the "Q virus". During the beam test we were able to circumvent this by using a fast cool down of the cavity from 170 K to 4.2 K. In the near future we plan to heat treat this cavity to remove the hydrogen contamination.

A second cavity has been manufactured and delivered by ACCEL and will soon be tested. This cavity differs from the first one only with the addition of two RF probes in the Nb, one on the round beam tube and one in the waveguide just before the coupler. Mechanical measurements and final chemical cleaning of this cavity will be performed at Cornell as soon as the cavity arrives. Vertical cryostat tests should begin before the end of October. This cavity will be used in the final assembly of the Mk 2 cryostat.

The order has already been placed for the Niobium for the 3rd thru 5th cavities so that the long material delivery time delay can be avoided in the procurement of these later cavities.

CRYOSTAT DEVELOPMENT

The cryostat used in the first beam test was very tall. This presented no difficulty during the installation for the beam test in the high bay area near the CLEO detector. This location is, however, not available for a long term test so the next and all subsequent cryostat/cavities must fit in the 8 foot high accelerator tunnel.

The Mk 1 cryostat worked extremely well, the heat leak was as calculated, namely 25-30 Watts, and the assembly, while not easy, was possible. During the beam test two control loops were closed on the cryostat. The first controlled the liquid helium level in the cryostat by varying the input helium valve. The second controlled the pressure in the helium vessel by varying a valve in the cold helium gas return line.

A Mk 2 cryostat design evolved that met the new requirements without a complete redesign that would have required an additional testing phase. The cavity and beam line components are unchanged from the Mk 1 design, but the cryostat is turned upside down so that the waveguide feed is from the bottom with the RF window lying beneath the cryostat. The cryostat vacuum vessel was made somewhat narrower but somewhat higher. All cryogen feed and return lines will be on the fix end portions of the cryostat.

RF WINDOW DEVELOPMENT

We have previously reported the development of a high power RF vacuum window manufactured by Gamma/Premier. This window was used during our CESR beam test and performed as described. Both our ability to process the cavity to higher gradients and the maximum power that we could transfer to the beam were limited by fast vacuum deterioration at the window. Since then we procured another pair of windows from Thomson. The results of these tests have been described in detail. A poster paper was presented by Eric Chojnacki at this workshop with further details on this window.

In summary, the window performed on a test stand much better than the Gamma window. CW power levels to 300 kWatts were obtained with a much shorter processing time. Pulsed power levels were achieved to 430 kWatts at 33% duty factor as well as 125 kWatts standing wave at all phases with a 50% duty factor. We tried a new "Trickle Processing" method with these Thomson windows. The results were very promising and we intend to utilize this method in the future. The technique is described in the reference.

In both the traveling wave and the standing wave tests we were limited by a temperature rise in the center of the ceramic disk to a value close to the limit imposed by the manufacturer (66 C maximum). Later decisions to raise this limit was hindered by the rather "weak" Klystron that was available. These tests will continue at a later time when the improved transmitter is available. We plan to procure another pair of this Thomson window design and to use this design, after more processing, on the Mk 2 cavity/cryostat.

HOM LOAD DEVELOPMENT

During the beam test a ferrite, beam line HOM load was installed at each end of the cavity. The performance was entirely satisfactory both with respect to adequately damping HOMs and also insofar as they were capable of handling the HOM power encountered in this test. We were aware that the solder bonds of the ferrite to the cooling panels was not completely uniform which could lead to difficulties at higher HOM power levels.

An additional test was made, off line, with the HOM loads under vacuum. This test in vacuum took the absorbed power level to 7 kWatts and later in air to 15 kWatts. These power levels were operational but it was clear upon observation with an infra-red camera that there were hot spots on the ferrite that were not adequately thermally bonded.

We also plan to extend the ferrite, on the fluted beam tube end, toward the cavity by an additional 2-3 cm. This has the effect of reducing the Q of one of the marginally troublesome transverse modes by a factor of two, well within the calculated requirements for the anticipated current levels.

REFRIGERATOR AND DISTRIBUTION SYSTEM

During the high power cavity/cryostat tests of last year, not having a dedicated refrigerator system, we borrowed the refrigerators normally used for the CLEO magnet. This system operated satisfactorily but was marginal with regard to the peak helium gas return levels that could be accommodated.

TESLA

Cornell has continued to participate in the TESLA meeting and presented significant material at the "Workshop on Cavity Fabrication Techniques" that was held March 6-8, 1995.

In the past year a four cell 1.3 GHz cavity has been fabricated using RRR= 500, Russian high purity Niobium. Two single , 1.3 GHz cavities and two 1.5 GHz cavities were also made from this material.

HPP STUDIES

Three 5 cell TESLA cavities that were tested at Cornell reached E_{acc} fields of 25 MV/m by HPP processing after titanium heat treatment. Recently a four cell cavity made with RRR= 500 Niobium was tested. During the first vertical test of this cavity the field was processed from E_{acc}= 14 MV/m to E_{acc}= 18 MV/m, limited by a quench.

Another series of measurements have been on the HPP test stand, measuring the instantaneous Q during the RF high power pulse. This technique has been used to measure H_c (RF) of these cavities reaching very high peak fields during the HPP processing. This technique has also been used to measure H_c (RF) of a cavity that had been coated with Nb_3Sn. The results of that experiment as well as other later results were reported by Tom Hays at a poster session at this workshop.

BASIC STUDIES

A new high resolution, high speed thermometry system has been built at Cornell and is being used on single cell 1.5 GHz Nb cavities. After a cavity test with these thermometers, the cavity is dissected for examination of those regions of interest with an electron microscope complete with EDX. We have examined electric field emitters that were active at the end of the test as well as emitters that were processed away during the test. Detailed results of this effort were presented in an invited talk by Jens Knobloch at this workshop.

FUTURE PLANS

A 1200 watt refrigerator system will be installed by 1996. A new cavity and a new compact cryostat are on order in preparation for a long-term test in CESR in 1996. Four cavities will be installed in 1998-1999 for CESR-III.

Most of the resources of the SRF group at Cornell will be dedicated to the task of designing, constructing, installing and testing SC RF cavities in CESR. Efforts directed to help in the TESLA collaboration will continue, mostly in the areas of HPP studies, calculations and consultations. Basic research efforts will continue in the areas of both thermal breakdown and field emission at a level approximately equal to the present effort.