Beam Test of a Superconducting Cavity for the CESR Luminosity Upgrade*

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ABSTRACT

The prototype superconducting cavity system for CESR-Phase III was tested in CESR in August 1994. The performance of the system was very gratifying. The cavity operated gradients of 4.5-6 MV/m and accelerated beam currents up to 220 mA. This current is a factor of 3 above the world record 67 mA for SRF[1]. The high circulating beam current did not increase the heat load or present any danger to the cavity. No instability attributable to the SRF cavity was encountered. A maximum of 155 kW of rf power was transferred to a 120 mA beam. The window was subjected to 125 kW reflected power and processed easily. In the travelling wave mode, vacuum bursts and arc trips prevented us from going above 165 kW. The maximum HOM power extracted was 2 kW. Beam stability studies were conducted for a variety of bunch configurations. In other tests a 120 mA beam was bumped horizontally and vertically by ±10 mm. While supporting a 100 mA beam, the cavity was axially deformed with the tuner by 0.4 mm to sweep the HOM frequencies across dangerous revolution harmonics. In all such tests, no resonant excitation of HOMs or beam instabilities were observed, which confirms that the potentially dangerous modes were damped strongly enough to be rendered harmless.

INTRODUCTION

The rationale for using superconducting cavities in high current storage rings is discussed in [2]. To increase the luminosity of CESR with currents of the order of 1 amp, a superconducting cavity is the ideal way to lower cavity impedances that cause multibunch instabilities. The impedance for CESR-III will be reduced by using a small number of high gradient (6 MV/m) superconducting cavities which have a low impedance cell shape.

Before the beam test, the niobium cavity was tested in the vertical cryostat to 3 MV (gradient = 10 MV/m) [3], the window was tested off-line to 250 kwatt travelling wave and 125 kwatt standing wave[4], the ferrite lined beam pipe HOM loads were tested to withstand a power density of 20 watt/cm^2[5].

Fig. 1 shows the cavity, cryostat, input coupler, planar window, ferrite beam pipe HOM couplers, tuner, gate valves,sliding joints, tapers to the CESR beam pipe, vacuum pumps, refrigerator interface box (cold box), and other components needed for the CESR beam test. The cavity was first tested in the processing area with high power without beam. Once it operated CW at 6 MV/m it was installed in the CESR beam line, in the high bay area, west of the CLEO detector. The refrigeration system consisted of two units, nominally rated at 100 watt, feeding into a 1000 litre dewar. The cold gas from the cryostat was returned to the refrigerator. On one side, CESR dipole magnets were located < 1 m away from the SRF cavity; but on the detector side, the closest magnet was > 15 m away. Therefore most of the high current tests were carried out with a positron beam, so as not to irradiate the cavity region with too high a synchrotron radiation (SR) dose from the nearby magnet. Near the end of the test, however, a 57 mA electron beam was also run through the cavity, to evaluate how the cavity would perform in the presence of a severe SR dose. 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) which is 1 mA less than the maximum total current ever run in CESR up to the time of the SRF beam test. The current limit was set not by the performance of the cavity but by the heating (80-100C) of CESR components, in particular the 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. Again, the heating of CESR components was the limit. 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.

Fig. 2 shows the response of the <u>total</u> cryogenic losses to the injection of high beam current. Starting at 5:30 am, as the beam was increased from 0 to 220 mA, there was no observable increase in total cryogenic loss (80 watt). Note however, the increase in heat load, from 50 to 80 watt, when the rf was turned on (before the beam) at 5:24 to establish a gradient of 4.7 MV/m (1.4 MV for the cell) 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.

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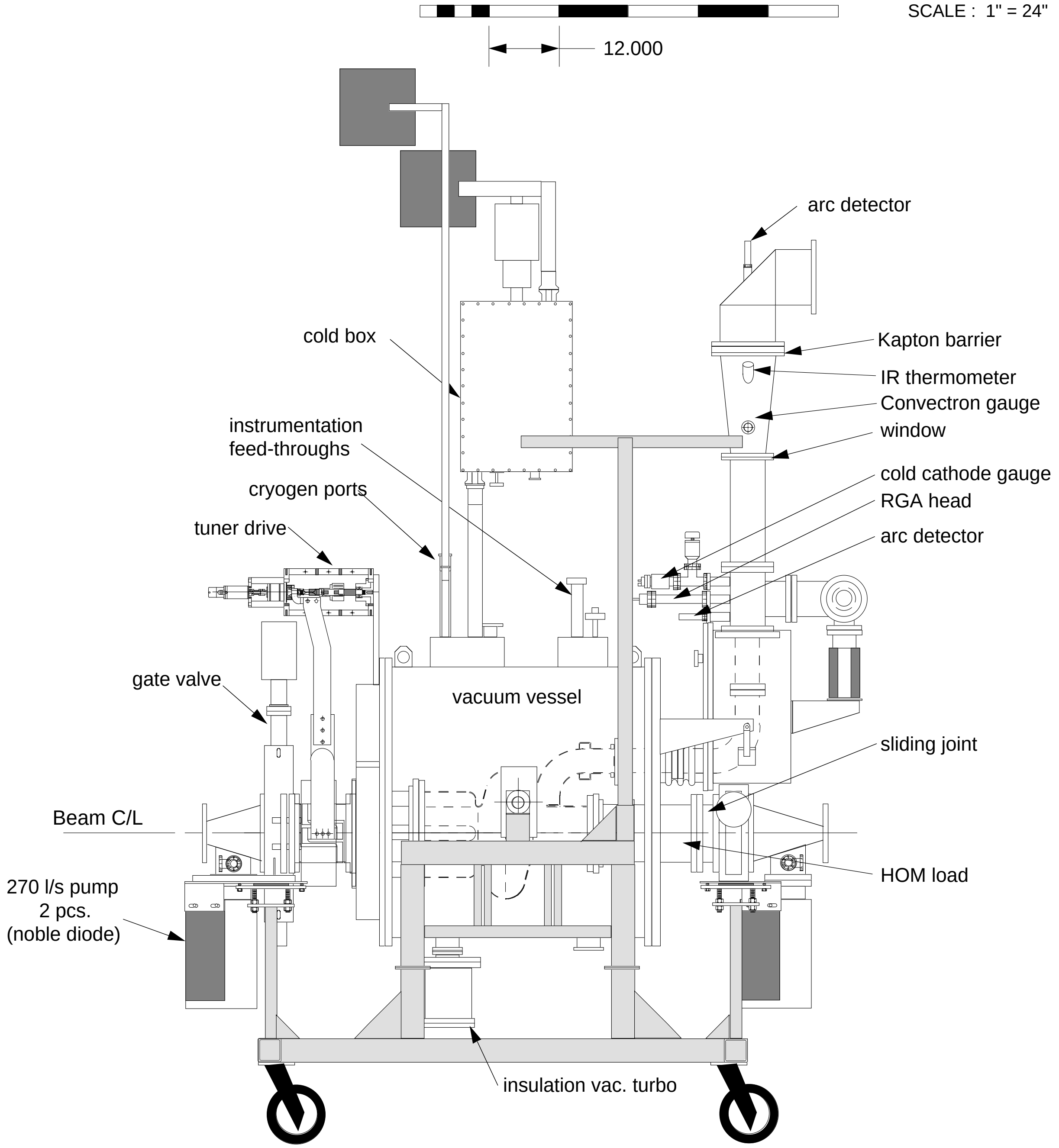

Fig. 1: Layout of all components the CESR high current beam test of the superconducting cavity.

HIGHER GRADIENT OPERATION

Fig. 3 shows the Q_0 vs. E_{acc} of the cavity as measured on-line, but without beam. We used a cold gas flow meter to continuously monitor the He mass flow, and cross calibrated the flow meter with a bath heater.

At 5.0 MV/m ($Q_0 = 10^9$) the cavity was run stably 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 as the cryostat pressure would rise steadily, requiring the tuner to keep moving to maintain the cavity at the right frequency. Eventually the tuner ran into its safety stop. Nevertheless we ran the cavity for short periods (few minutes) with beam currents between 95 and 120 mA and cavity gradient up to 6 MV/m.

DELIVERING BEAM POWER

As shown in Fig. 4, 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[1]. For the

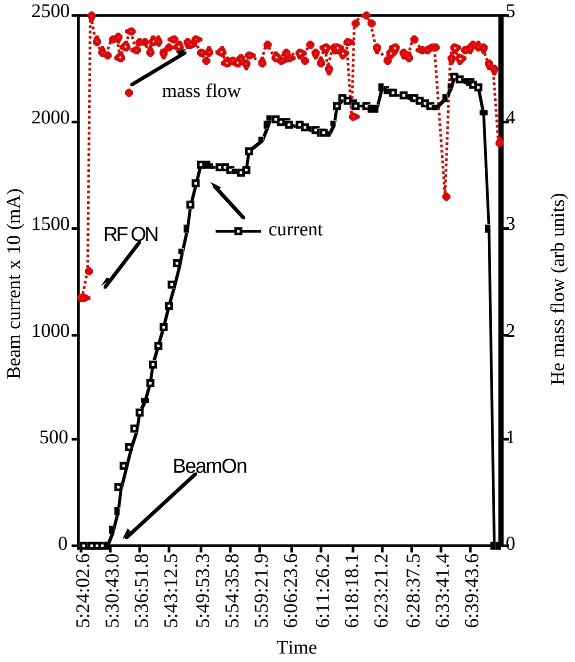

Fig. 2: Total cryogenic loss and beam current as a function of time. The cavity gradient for the record beam current run was 4.7 MV/m.

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.

With no beam, and with the SRF cavity off resonance, the window processed in less than one hour to 125 kW full reflected power. With beam and the cavity on resonance, processing took much longer (30 hours) and 42 trip events. Most of the trips were triggered by a vaccum degradation in the window region. Six trips were accompanied by light emission. (Note that between the high power, off line window test and the beam test, the window was let up to clean air for several days duirng assembly.)

OTHER TESTS

The performance of the HOM loads, the interaction of ferrite HOM loads with the beam, and beam stability studies are discussed in other papers at this conference[5,6]. Briefly, 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 chosing 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 uncoventional 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 $6\text{x}10^{-9}$ to $6\ \text{x}10^{-8}$ torr. The cavity operated stably in the presence of this large SR dose and there was no increase in cryogenic losses.

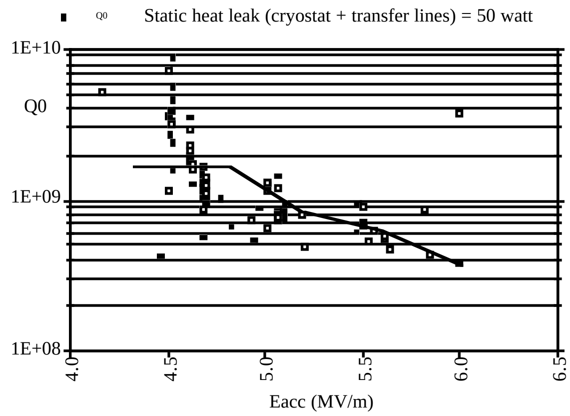

Fig. 3: Qo vs. Eacc meausred on line without beam

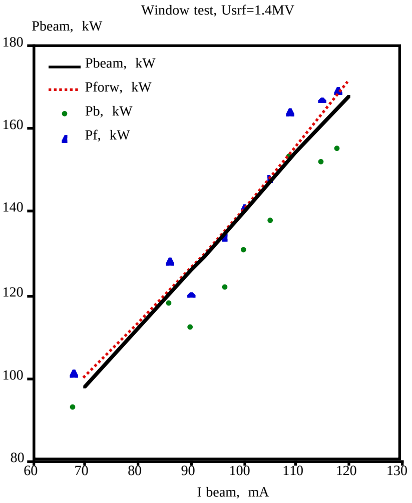

Fig. 4: Power delivered to the beam vs beam current. The operating gradient during these tests was 4.7 MV/m

CONCLUSIONS AND FUTURE

The SRF cavity stored the limit of current that CESR could deliver. For most of the test the cavity was run near 5 MV/m. A 100 mA beam was stored for a short time at 6 MV/m gradient. The input coupler and window delivered 155 kW to a 100 mA beam. A new window was received from Thomson and tested to 300 kW CW and 400 KW at 33-50% duty cycle[7]. 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.

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