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Performance Experience with the CEBAF SRF Cavities*

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Abstract

The full complement of 169 pairs of niobium superconducting cavities has been installed in the CEBAF accelerator. This paper surveys the performance characteristics of these cavities in vertical tests, commissioning in the tunnel, and operational experience to date. Although installed performance exceeds specifications, and 3.2 GeV beam has been delivered on target, present systems do not consistently preserve the high performance obtained in vertical dewar tests as operational capability. The principal sources of these limitations are discussed.

I. INTRODUCTION

The CEBAF recirculating linac uses 338 superconducting rf cavities to accelerate the beam. With four passes through the linacs, 3.2 GeV beam has been delivered onto a target. Operation to date has been limited to low current, pulsed beam. As commissioning continues, the delivery of 200 μA CW beam at > 4 GeV is anticipated. Installed capacity may support operation above 5 GeV.

This paper reviews the characteristics and performance of the CEBAF SRF cavities. The cavities are but a part of the integrated system which delivers beam for nuclear physics research. At the start of the construction project these cavities together with the attendant 2 K liquid helium system were considered to present considerable technical risk. High-quality performance by our vendor [1] and careful attention to QA procedures, though, have resulted in the cavities performing reliably well above their design specifications of E_{acc} = 5 MV/m in qualifying tests.

Performance summaries have been presented previously for subsets of the cavities.[2–6] Process details described there will not be repeated here.

II. CAVITY PERFORMANCE AND LIMITATIONS

A. Cavity Performance Parameters

CEBAF was able to exploit a tested SRF cavity design developed at Cornell University for storage ring applications.[7] With only minor modifications, the cavity design was directly applicable to CEBAF. The nominal values of various parameters of the cavity are collected in Table 1. The principal figures of merit, of course, are the accelerating gradient and the unloaded quality factor (Q_0).

The CEBAF five-cell cavities were assembled and tested as pair units prior to assembly of four pairs into the horizontal cryomodules. In this cryomodule configuration, the cavities were commissioned for operation in the accelerator tunnel. Systematic performance tests in this configuration are difficult, principally because Q_0 must be measured calorimetrically.

SRF cavity performance is the combination of:

(1) physical design factors—these determine the beam-cavity interaction characteristics,

Table 1: CEBAF SRF Cavity Design Parameters

fundamental frequency	1497.0 MHz
accelerating gradient, E_{acc}	> 5 MV/m
active length	0.5 m
cell-to-cell coupling	(3.09 ± .02)%
geometry factor	275 Ω
R/Q	960 Ω/m
E_{pk}/E_{acc}	2.56
Q_{ext} input coupler	$6.6 \times 10^6 \pm 20\%$
tuner phase error budget	10°
microphonic phase error budget	30°
Lorentz force frequency sensitivity	-2.2 Hz/(E_{acc}[MV/m])^2
pressure frequency sensitivity	80–137 Hz/torr
niobium RRR	≥ 250
HOM Q_l - 1976 MHz mode	4000
HOM Q_l - 1980 MHz mode	1800
beampipe ID	70.4 mm
At E_{acc} = 5 MV/m:	
Q_0	$\geq 2.4 \times 10^9$
2 K dynamic heat load	< 2 W
x-plane effective dipole steering	7.5×10^{-3} MeV/c
y-plane effective dipole steering	-1.7×10^{-3} MeV/c
effective normal quadrupole	1.2×10^{-3} MeV/c/cm
effective skew quadrupole	-1×10^{-3} MeV/c/cm

(2) material and surface dependent factors—these determine the maximum sustainable stored energy and the 2 K heat load,

(3) extrinsic operability factors—these include availability of rf drive, total 2 K cooling capacity, and reliability concerns such as frequency of interruptions to operations due to interlock trips.

The design factors have been well characterized elsewhere,[4,7,8] and the principal parameters are included in Table 1. The particular limitations of each cavity were established during the vertical cryostat tests, and the integrated system limitations have been determined from cryomodule commissioning and accumulating operating experience.

B. Performance Limitations

Using the hermetic cavity pair configuration and coax-to-waveguide variable couplers,[9] CEBAF characterized the cavity-specific factors of all cavities in a vertical dewar testing arrangement. This test also provided a thorough leak-check of the assemblage. The ceramic rf windows are attached to the cavity prior to this test, and are thus part of the tested system, as are the higher-order-mode loads and beamline gate valves.

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III. CURRENT OPERATING CONDITIONS

During the installation and commissioning of individual cryomodules, cavity gradient and Q performance were tested, and stable operating bounds were established for short periods of time. The limiting constraint was noted for each cavity. To these limits the operational derating due to arcing has been added. The present distribution of types of cavity gradient limitations is provided in Figure 6. Clearly, the arcing and electron loading limitations, which as mentioned above we believe to be coupled, represent the most significant gradient performance constraints for CEBAF.

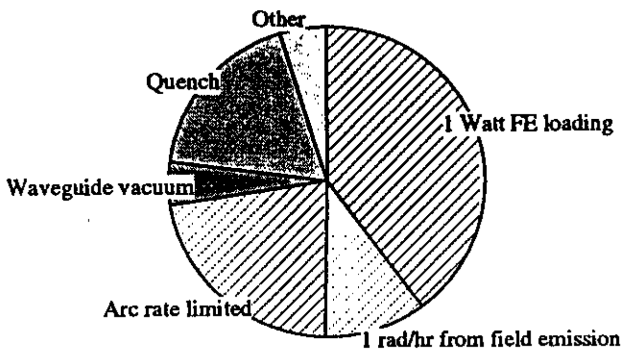

Figure 6. Distribution by type of cavity performance limitation—commissioning and operating experience

The installed cryomodules and rf drive systems are currently set up to support delivery of 15 μA, 4 GeV beam on Hall C targets. To reduce the consumption of ac line power during low current commissioning, the klystron supplies have been set to a lower tap setting. This has limited the available rf power per klystron to about 1.7 kW, down from their full 5 kW capability. This change has also had the benefit of extending the MTBF of the klystrons.

The present view of CEBAF SRF cavity operating performance is depicted in Figure 7 on a per-cryomodule basis. Five cavities are turned off, three with locked tuners, one with a broken interlock sensor, and one with a defective rf pickup probe. The operational derating of cavities has reduced the net usable voltage by 5% relative to commissioning test data.

In the fall of 1995, we anticipate raising the tap settings to accommodate higher current operation. Under those conditions we expect significantly higher performance from the SRF cavities—supporting up to 200 μA beam at energies greater than 5 GeV. At that time we plan to examine the arcing behavior of cavities that otherwise function well at high gradients. The CEBAF acceleration system now appears capable of supporting operation at least 25% above initial design requirements. We envision opportunities for further improvements toward yet higher energies.

IV. ACKNOWLEGEMENTS

The staff of the SRF and RF groups are pleased to have provided and commissioned the acceleration system for CEBAF. Particular credit goes to R. Sundelin and P. Kneisel for their work designing and refining the core building blocks of the accelerator. Production assembly and commissioning of cryomodules was coordinated by H. F. Dylla and W. Schneider.

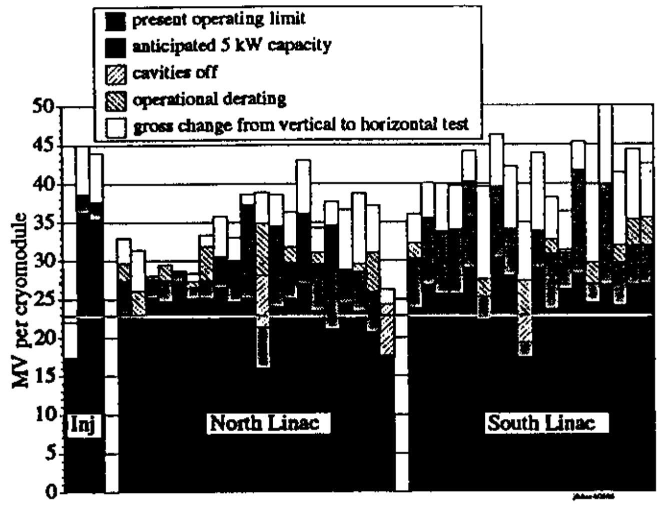

Figure 7. Capability of installed CEBAF cryomodules.

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