HIGH CURRENT OPERATION OF THE CORNELL ERL SUPERCONDUCTING RF INJECTOR CRYOMODULE*

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Abstract

Cornell University has developed a SCRF injector cryomodule for the acceleration of high current, low emittance beams in continuous wave operation. This cryomodule is based on superconducting RF technology, and is currently under extensive testing in the Cornell ERL injector prototype with CW beam currents exceeding 50 mA. Strong damping of Higher-Order-Modes in the cavities is essential for high beam current operation, and is achieved by beamline RF absorber located at cryogenic temperatures in the beam pipe sections between the cavities. This paper gives an overview of the experience gained during the high beam current operation of the cryomodule.

INTRODUCTION

Cornell University's Laboratory for Accelerator based Sciences and Education is currently conducting an extensive R&D program to fully develop the SRF technology for a 5 GeV, 100 mA Energy-Recovery Linac (ERL) [1]. This work includes a short SRF section in the ERL injector as well as a multi-GeV main linac operated in CW mode in the ERL loop. The main challenges for these SRF sections arise from the CW operation of the cavities and from supporting very high beam currents. An overview of these ERL related SRF activities at Cornell University is given in [2]

The Cornell ERL SRF injector sectio will host 12 SRF 2-cell 1.3 GHz cavities [3] providing a total energy gain of up to 15 MeV. A 5 cavity prototype version of this cryomodule has been developed [4] and fabricated at Cornell, and is now under operation in the Cornell high current ERL prototype [5]. The injector cryomodule is shown in Fig. 1, and key parameters are listed in Table 1.

Extensive tests of the injector module have shown that it meets and exceeds specifications for cavity performance, coupler performance, cavity alignment, and field stability [6]. In this paper we discuss high beam current operation of the injector cryomodule at record beam currents and damping of Higher-Order-Modes (HOMs).

INJECTOR SRF CRYOMODULE

For details on the module design refer to [4]. The injector cryomodule hosts 5 superconducting 1.3 GHz 2-cell cavities [3]. Each cavity is powered by an individual high power (120 kW) CW klystron, with the RF power being coupled into each cavity via a symmetric twin high power input coupler [7]. High beam current operation requires strong damping of Higher-Order-Modes (HOM) in the SRF cavities, which is achieved by beamline HOM absorbers located between the cavities [8]. The loads must operate cold, with an 80K heat intercept provided by high pressure Helium gas. Three types of RF absorbers are used to provide broadband RF absorption (two ferrite materials, TT2-111R and Co2Z, and a lossy ceramics, 137ZR10).

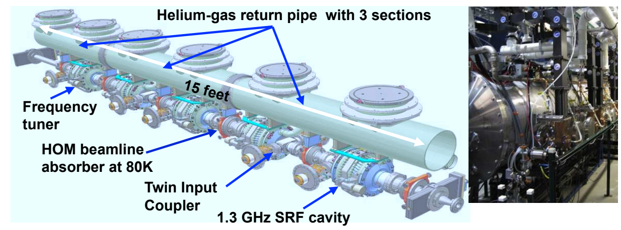

Figure 1: Left: CAD model of the cold mass of the ERL injector module with 5 SRF cavities and HOM beamline absorbers in between. Right: Injector module installed in the Cornell ERL injector prototype.

Table 1: Injector Specifications

	injector
Number of cavities	5
Number of cells per cavity	2
Accelerating gradient	5-15MV/m
Fundamental mode frequency	1.3GHz
Loaded quality factor	4.6×10^4
RF power per cavity	120kW
Required amplitude stab. (rms)	1×10^{-4}
Required phase stab. (rms)	$0.1°$
Design beam current	100mA
Total 2K / 5K / 80K loads	26/60/700W
Overall length	5.0m

HOM DAMPING

Simulations of the HOMs in the 5-cavity beamline of the injector cryomodule predict very efficient damping of these modes by the beamline absorbers between the cavities, see Fig. 2, with typical quality factors of a few 100 to few 1000. This was confirmed experimentally in the injector cryomodule by exciting the HOMs via pick-up antennas located at the cavity beam tubes and at the HOM loads; see

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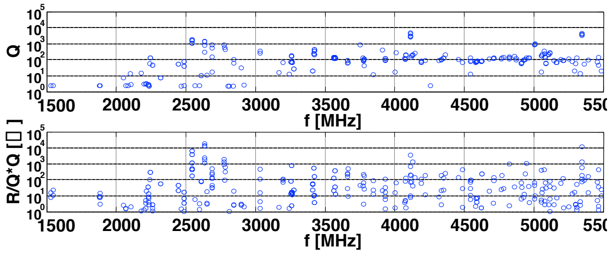

Figure 2: CLANS simulation results for monopole higher-order modes in the 5 cavity beamline of the injector cryomodule. Top: Quality factor. Bottom: $(R/Q)Q$.

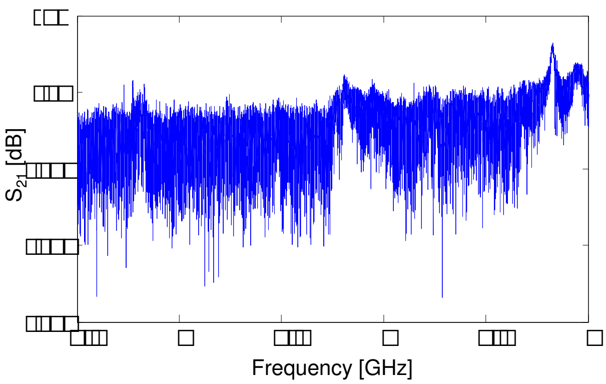

Figure 3: Vector network analyzer scan for HOMs between 1.5 GHz to 4 GHz. Shown is the transmission amplitude vs. scan frequency. Pick-up antennas on the cavities and HOM loads were used to couple to the HOMs.

Fig. 3. Preliminary results show very strong suppression of monopole and dipole modes with typical quality factors of only a few 1000.

HIGH CURRENT OPERATION

Fig. 4 shows beam current vs. time during two recent CW high beam current operations of the injector cryomodule with 1.3 GHz bunch repetition rate and $\approx$ 2 ps bunch length. As shown, the module was operated continuously for several hours at 20 mA, and for shorter term with CW beam currents of up to 50 mA, setting a new record for this type of SRF linac operation.

Temperature measurements at the HOM beamline loads showed only small temperature increases at these high current runs, as expected from absorbing the HOM power excited by the beam. Measuring the increase in cooling gas temperature in the HOM loads allows for estimating the RF power absorbed by the absorbers. Preliminary measurements show good agreement of the total power absorbed with results from wakefield and longitudinal loss factor simulations [9].

Temperature sensors mounted on the shielded bellow sections in the HOM beamline absorbers and elsewhere on the beamline showed no significant temperature increases during the high beam current runs. During 50 mA operation, 50 kW of RF power per SRF cavity were coupled into each cavity by twin input couplers and transferred to the beam. The spectrum of the HOMs excited by the beam current was measured for 50 MHz and 1300 MHz bunch repetition rate; see Fig.5 The total HOM power and the spectra showed the expected behavior with varying beam current and bunch repetition rate ($P \propto I^2/T_{rep}$), and showed no weakly damped HOMs.

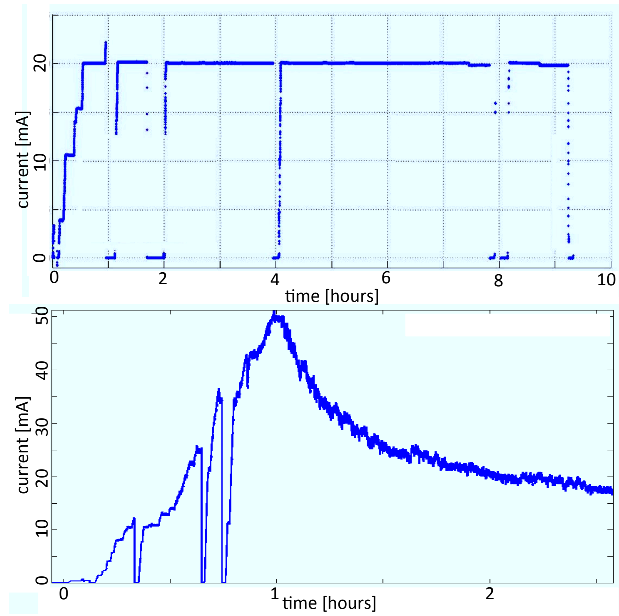

Figure 4: Beam current vs. time during high current operation of the injector cryomodule (cw operation , 1.3 GHz bunch repetition rate). Top: 8 hour operation at 20 mA. Bottom: Operation at record beam current of 52 mA.

OUTLOOK

Future work will focus on detailed measurements of the HOM power absorbed by the HOM beamline loads at high cw beam currents. This will allow determining the longitudinal loss factor of the entire beam line as function of bunch length. It is planned to further increase the beam current in the Cornell ERL injector prototype towards the full 100 mA specification. Based on the HOM and high beam current operation results presented here, we expect that the HOM damping scheme of the injector cryomodule will support operation at the full 100 mA.

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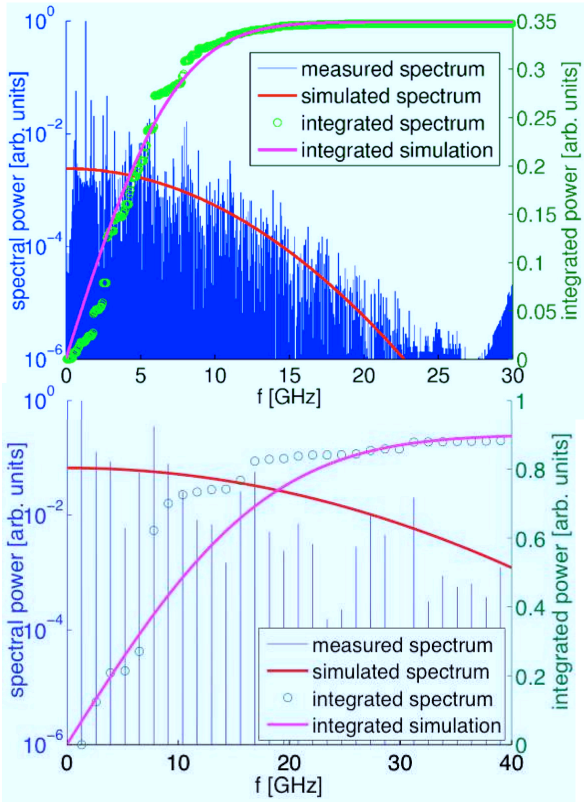

Figure 5: HOM spectrum excited by the beam as measured at one of the HOM loads. The integrated spectrum is plotted on the secondary axis. Also shown are results obtained by ABCI simulations for the entire beamline in the injector module [9]. Top: 50 MHz bunch repetition rate. Bottom: 1.3 GHz bunch repetition rate.

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