FIRST TEST RESULTS FROM THE CORNELL ERL INJECTOR CRYOMODULE*

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Abstract

Cornell University has developed and fabricated a 5 cavity SRF injector cryomodule for the acceleration of a high current (100 mA), ultra low emittance beam. This cryomodule has been installed in the Cornell ERL prototype, and is presently under extensive test. The combination of a high beam current with emittance preservation of an ultra low emittance beam results in a multitude of challenges for the SRF system, pushing parameters well beyond present state of the art. Strong HOM damping and effective HOM power extraction is required to support the 100 mA beam current. This is achieved by placing HOM beam line absorbers between all cavities. Emittance preservation is addressed by a symmetric beam line with twin input couplers, tight cavity alignment and the option of fine alignment of cold cavities. In this paper we report on first results from the injector module test, including results from the cool-down, static heat load measurements, and initial cavity performance tests.

INTRODUCTION

Cornell University's Laboratory for Accelerator based Sciences and Education (CLASSE) is exploring the potential of a x-ray light source based on the Energy-Recovery-Linac (ERL) principle [1]. This type of light source promises superior X-ray performance as compared to conventional third generation light sources [2], but several accelerator physics and technology challenges need to be addressed before a full energy ERL light source can be built. These challenges result primarily from the high current, ultra low emittance beam required at the undulator locations beyond.

To study and demonstrate the production and preservation of such an ultra-low emittance beam, a prototype of the ERL injector [3] is presently under construction and commissioning at Cornell. One of the most challenging and critical components in the injector is its energy booster cryomodule, hosting five superconducting (SC) 2-cell 1.3 GHz cavities. The main challenges facing this cryomodule are (1) the acceleration of a high current beam with up to 500 kW of total power transferred to the beam, (2) significant Higher-Order Mode (HOM) excitation in the SRF cavities up to frequencies of tens of GHz by the high current beam, and (3) the preservation of the ultra-low emittance of the electron beam while it passes through the cryomodule. Solutions to all these challenges have been found, and prototypes of the main beam line components (SRF cavities, HOM loads, and input couplers) have been developed, fabricated and tested [4]. Following the successful test of a horizontal test cryomodule [5], the full ERL injector SRF cryomodule has been designed [6] and fabricated [7]. Table 1 lists some key specifications of this cryomodule. Recently, the injector cryomodule has been installed in the Cornell ERL injector prototype, and commissioning has started. Figure 1 shows a layout of the injector. The SRF module is located about four feet downstream of the DC gun; see also Figure 2. The five SRF cavities in the module are powered by individual high power (120 kW) CW klystrons, located on a mezzanine above the injector prototype. The commissioning of the injector RF system is described in detail in [8]. In the following we present initial results for the commissioning of the SRF injector module itself.

Table 1: ERL injector cryomodule specifications

Number of 2-cell cavities	5
Accelerating voltage per 2-cell cavity	1 – 3 MV
Fundamental mode frequency	1.3 GHz
R/Q (linac definition) per cavity	222 Ohm
Qext	$4.6\times10^4 – 4.1\times10^5$
RF power per cavity	100 kW
Required amplit. / phase stability (rms)	9.5×10^{-4} / 0.1°
Maximum beam current	100 mA

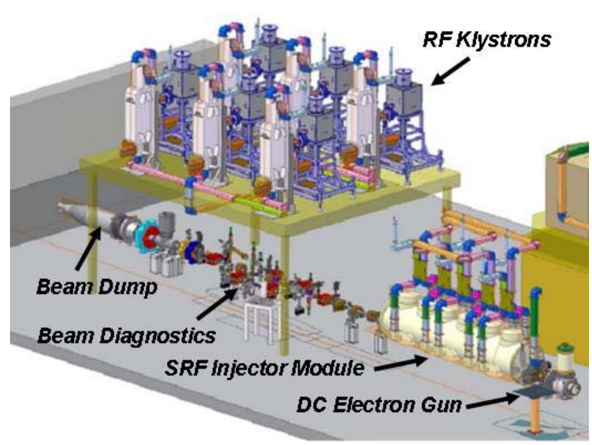

Figure 1: Layout of the ERL injector prototype.

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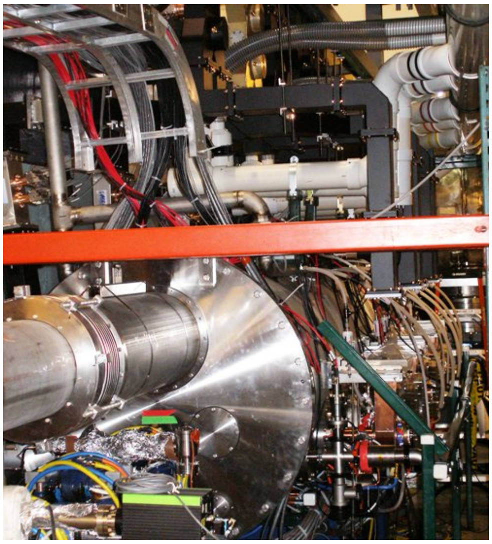

Figure 2: Injector cryomodule in the prototype ERL injector.

COOL-DOWN

The cryomodule was cooled down from room temperature to 4.2 K over a period of 2.5 days. Above 80K, the cool-down rate was limited to <10K/hour to reduce thermal stress on components like the helium-gas return pipe, the 80K thermal shield and the absorber tiles in the HOM loads. The 80K, 5K, and 1.8K systems of the cryomodule were lowered in temperature uniformly down to 80K, again to minimize thermal stresses. Figure 3 shows the temperature of the LHe-vessel of one of the SRF cavities in the module. Following cool-down to 4.2K, the temperature of the cavities was lowered to 1.8K by reducing the saturated pressure of the helium bath to about 12 torr. No problems or leaks were found during module cool-down.

Fundamental mode frequencies of all cavities were measured after cool-down at 4.2 K. Prior to any tuning of the cold cavities a frequency spread of only ±17 kHz was found.

During cool-down, the shift in positions of the cavities was monitored by a wire-position-monitor (WPM) system, which is installed in the module.

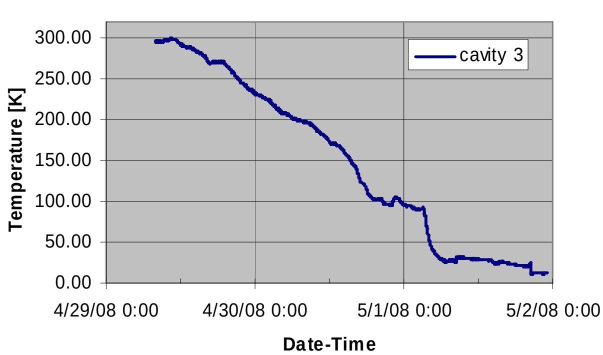

Figure 3: Temperature of cavity #3 during module cool-down.

To each cavity, a WPM block is directly mounted, allowing measuring the horizontal and vertical positions of the cavities independently. The measured positions of the WPM blocks on cavities and their shifts during cool-down are shown in Figure 4. The cavities shift upwards during cool-down due to thermal shrinkage of the cavity support structure. The average upward shift measured is 0.8 mm, with a maximum deviation of only ±0.1 mm. This is in very good agreement with the expected shift of 0.9 mm. Horizontally the WPM blocks shift by an average of 0.6 mm (as expected), because they are mounted about 20 cm to the side of the cavities, and the horizontal centers of the cavities remain fixed. Accordingly, during cool-down the horizontal positions of the cavities have shifted by less than ±0.2 mm.

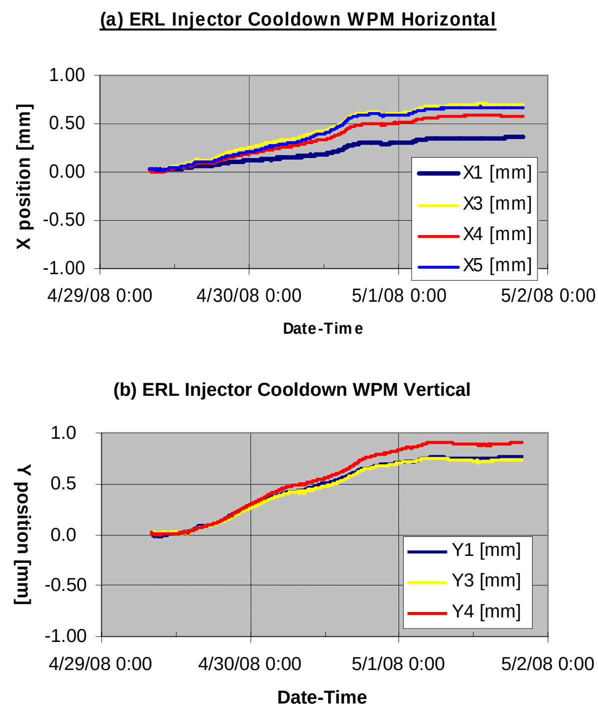

Figure 4: WPM data during cool-down of the injector module. (a) Horizontal position of WPM blocks on cavities 1, 3, 4, and 5. (b) Vertical position of WPM blocks on cavities 1, 3, and 4. WPM #2 is not functional.

STATIC HEAT LOAD

The static heat leak to 1.8K was measured by closing the JT valve in the LHe feed and measuring the drop of the LHe level over time. Heaters on the 1.8K system were used to calibrate the drop in level. Preliminary measurements show a static heat leak to 1.8K of 10±3 W. The heat leak to 1.8K is dominated by thermal conduction from 5K intercepts in the input couplers, helium-gas return pipe support posts and HOM loads to the 1.8 K system. Currently, the 5K system of the cryomodule is cooled by 5.5K high pressure helium gas. For these conditions, the expected static heat leak is 9 W, in good agreement with the measured value.

INITIAL CAVITY PERFORMANCE

The initial performance test of the five superconducting 1.3 GHz 2-cell cavities in the injector module has started. As of writing, three of the cavities have been tested successfully. In this initial phase of the commissioning, cavities will be tested and operated up to an accelerating voltage of 1 MV (corresponding to about 5 MV/m) only, as required for the baseline beam energy gain of 5 MeV total. Both cavities tested were brought to this field level within minutes after turning on RF, see Figure 5. No quenches or other cavity performance related events like multipacting occurred during increasing the fields. No x-rays were detected outside of the cryomodule, indicating sufficient cleanness during cavity preparation and module string assembly. Preliminary estimates of the intrinsic quality factors Q_0 of the three cavities at 5 MV/m give values above 10^{10} at 1.8K. These high intrinsic quality factors are a clear indication that the absorber tiles in the HOM loads survived the thermal stresses during cool-down without breaking and generating dust particles. During the test of the horizontal test cryomodule a low cavity Q of about $1.5 \cdot 10^9$ was found [5], caused by dust particles generated by ferrite tiles in the large diameter HOM loads, which broke as a result of thermal stress during cool-down. Only the largest tiles of the ferrite type TT2-111R failed. These tiles were removed from the HOM loads for the full injector cryomodule and replaced by tiles of the same size, but made out of one of the other two RF absorbing materials used in the loads.

During the performance test, the cavities are operated at a loaded Q of about 10^6. A new generation of the Cornell low level RF (LLRF) controls has been developed and is used for precise cavity field regulation for the cavities in the ERL injector [8]. In a first test of the new LLRF system with one of the SRF cavities, an rms amplitude stability of 10^{-4} and rms phase stability of 0.05° were achieved, exceeding the ERL injector requirements.

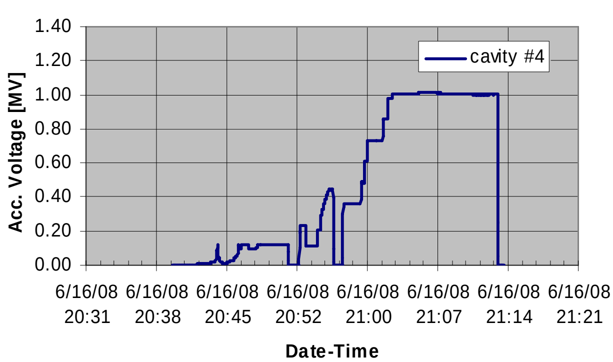

Figure 5: First ramp up of field in cavity #4.

SUMMARY

The Cornell ERL injector cryomodule is installed in the ERL injector prototype, and commissioning is in its early phase. The module was cooled down successfully. Static heat loads are as expected. Excellent cavity alignment within ±0.2 mm after cool-down was verified. Initial tests of the cavities show good cavity performance with no indications of failed absorber tiles in the HOM loads.

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