HIGH POWER TESTS OF INPUT COUPLERS FOR CORNELL ERL INJECTOR*

V. Veshcherevich†, S. Belomestnykh, P. Quigley, J. Reilly, and J. Sears
(Cornell University, Ithaca, NY, USA))

Abstract

RF power couplers for the ERL injector, currently under construction at Cornell University, have been fabricated. The couplers were assembled in pairs in the liquid nitrogen cryostat, built for their tests. First two prototype couplers were tested using an IOT transmitter and a resonant ring for additional power amplification. They were tested up to the goal power level of 50 kW CW and used later for tests of the first injector cavity. However, the first pair of couplers showed excessive temperature rise in some points. Therefore, minor changes in the design have been done to improve cooling. The couplers of updated design were successfully tested from a klystron up to the power level of 60 kW CW. *In situ* baking was implemented for coupler installed in the cryostat.

INTRODUCTION

The Energy Recovery Linac (ERL) injector is under construction at Cornell University [1]. It will be a CW linac with photocathode DC gun operating in the energy range from 5 to 15 MeV with a high average current (100 to 33 mA). Five two-cell 1300 MHz RF structures will comprise the superconducting portion of the machine.

The input coupler is one of the key components of the injector cavities due to strict requirements such as a high CW power transferred to the beam (up to 100 kW), strong coupling, wide range of coupling adjustment, and small distortion of transverse beam motion. Each injector cavity is equipped with two identical antenna type couplers symmetrically attached to a beam pipe of the cavity. This is a remedy to reduce RF power per single coupler, coupling to the cavity, and the transverse kick to the beam.

The coupler was designed [2] and two prototype units have been manufactured and tested. This paper presents test results and discusses design improvements that are applied to ten couplers of production series ordered from CPI/Beverly as well as test results of first production couplers.

COUPLER DESIGN

The design of the ERL Injector couplers is based on the design of TTF III input coupler [3]. It has, however, been significantly updated [2]:

1. The cold part was completely redesigned using a 62 mm, 60 Ω coaxial line (instead of a 40 mm, 70 Ω line) for stronger coupling, better power handling, and avoiding multipacting.
2. The antenna tip was enlarged and shaped for stronger coupling.
3. The "cold" window was enlarged to the size of the "warm" window.
4. The outer conductor bellows design (both in warm and cold coaxial lines) was improved for better cooling (heat intercepts were added).
5. Forced air cooling of the warm inner conductor bellows and "warm" ceramic window was added.

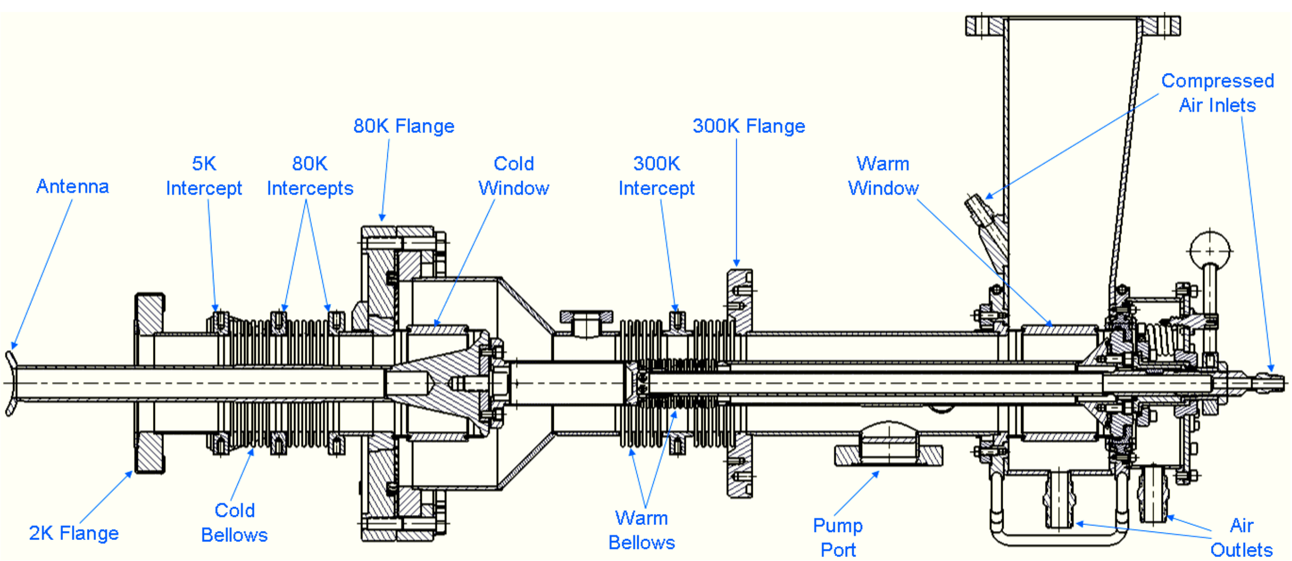

Figure 1: 2D section view of the injector cavity coupler.

* Supported by the National Science Foundation grant PHY 0131508.
† vgv@lepp.cornell.edu

Table 1: Parameters of Couplers

Central frequency	1300 MHz
Bandwidth	±10 MHz
Maximum RF power transferred to matched load	65 kW
Number of ceramic windows	2
Q_{ext} range	9.2×10^4 to 8.2×10^5
Cold coaxial line impedance	60 Ω
Warm coaxial line impedance	46 Ω
Coaxial line OD	62 mm
Antenna stroke	16 mm
Heat leak to 2 K	< 0.2 W
Heat leak to 5 K	< 3 W
Heat leak to 80 K	< 75 W

The parameters of couplers for the injector cavities are summarized in Table 1. The general design of the coupler is shown in Figure 1.

Twelve couplers have been ordered from CPI/Beverly. Two prototype couplers were manufactured and tested last year [4]; two production couplers were tested this year.

HIGH POWER TESTS

A traditional scheme was used for coupler tests: two couplers connected in series, with a coupling device included between them. As the coupling device, a cavity with very strong coupling was used.

It is important to keep the cold portion of the couplers at low temperature (at around 80 K) rather than at room temperature during the high power tests, because at room temperature the loss in metal and in "cold" ceramic window is higher and the thermal conductivity of copper and ceramics is significantly worse than at low temperature. That would lead to excessive heating and possible failure of the "cold" ceramic window.

To this end, a special liquid nitrogen cryostat with a copper coupling cavity inside has been designed and built for coupler tests. The whole cold portion of couplers is cooled to 80 K. Figure 2 shows the assembly of this test nitrogen cryostat with a coupling cavity and two couplers.

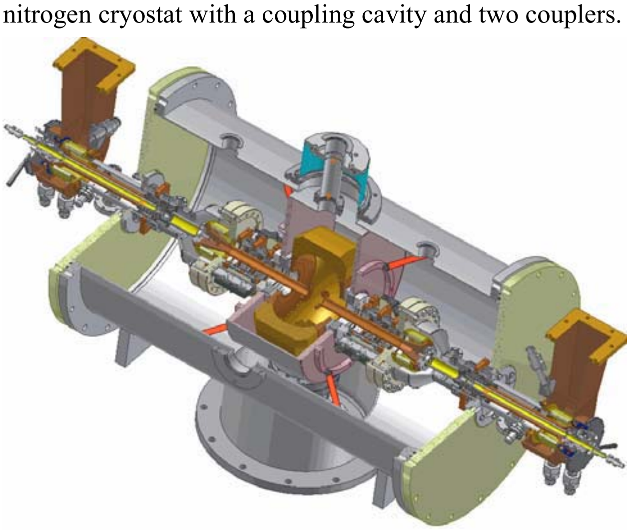

Figure 2: Nitrogen cryostat assembled with coupling cavity and two couplers.

Prior to the test, the prototype couplers were attached to the coupling cavity and baked under vacuum at 150°C in open cryostat. Then the "warm" portions of couplers were disassembled and reassembled with the closed cryostat for test. The "cold" portions of couplers were kept under vacuum all the time.

The test in that cryostat was well instrumented. The instrumentation included the following elements:

- Cold cathode gauges and ion pump currents
- Temperature sensors at various points inside and outside the cryostat: CLTSs, thermocouples, IR sensors, and an IR camera
- RF detectors
- Arc detectors (in warm portion of the couplers near the "warm" window)
- Cooling gas flow meters

A high power klystron was not available at the time of the prototype couplers test. Therefore, we used a 16 kW CW IOT transmitter (made by Thales) and built a resonant ring for additional power amplification. The coupler string was inserted into the resonant ring, which had a gain of 15 dB.

No significant vacuum activity in the couplers was observed up to power of 20 kW. Nevertheless, it was difficult to proceed further due to strong vacuum activity in the warm portion of both couplers. CW processing did not help. However, pulsed processing (with power up to 80 kW and pulse length from 10 µsec to 1 msec, total time 21 hrs) turned out to be very effective. We reached 50 kW CW but it was difficult to keep the resonant ring tuned for a long time due to thermal drifting. We lowered power to around 35 kW and stayed at this level for several hours.

During the tests, we observed unexpectedly high temperatures (~80°C) in the warm portion of the couplers (both outer and inner conductors). We could not reach equilibrium after staying several hours at 35 kW. Measured time constant was of 3 to 5 hrs.

Thermal analysis confirmed very long thermal time constant and revealed a possibility of thermal run-away. Therefore, we had to modify the design, replacing some of stainless steel parts of outer conductor in the "cold" window area with copper ones. We also added water cooling of the waveguide to reduce waveguide temperature near the "warm" window which exceeded

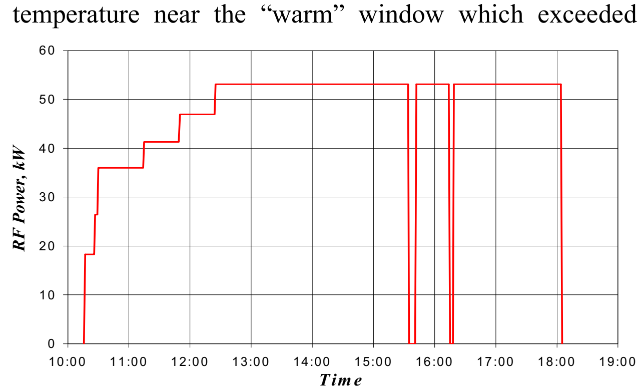

Figure 3: CW power delivered to production couplers during the 53 kW test. There were two klystron power supply trips (at 15:35 and 16:15) not related to couplers.

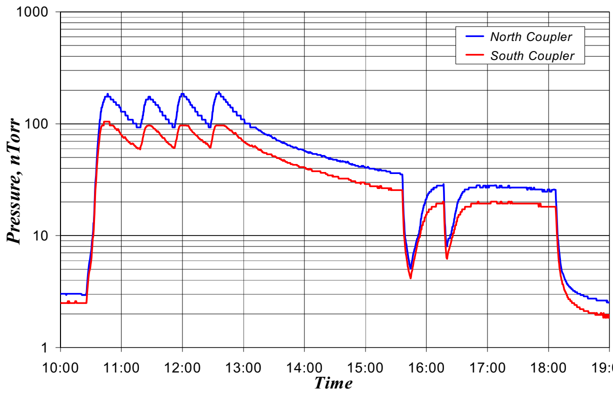

Figure 4: Vacuum in "warm" portion of couplers during the 53 kW test.

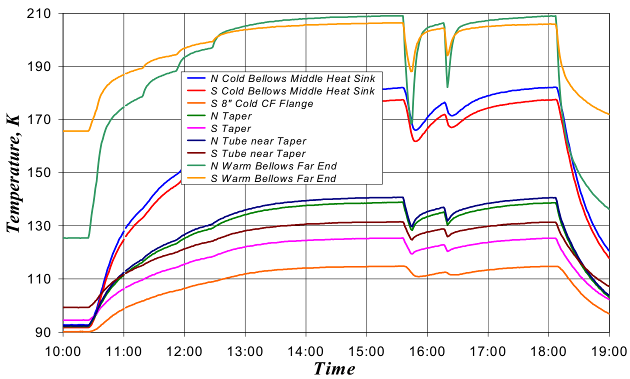

Figure 5: Temperatures in cold zone of "cold" and "warm" portions of couplers during the 53 kW test.

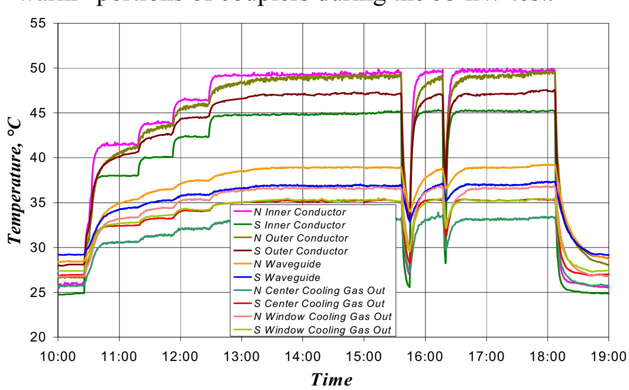

Figure 6: Temperatures of inner and outer tubes in "warm" portion of couplers during the 53 kW test.

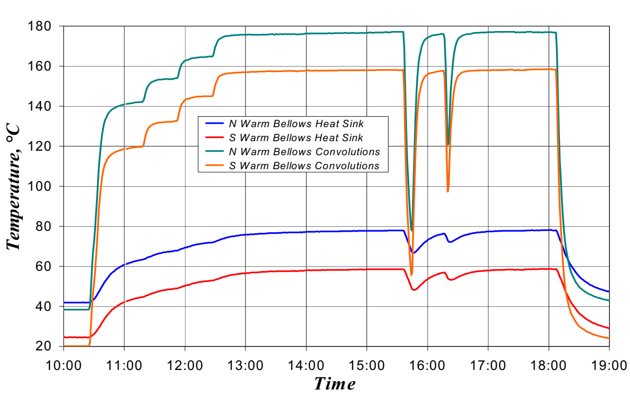

Figure 7: Temperatures related to the "warm" bellows in the outer tube during the 53 kW test.

40°C at 35 kW. We have ordered ten more couplers of the updated design.

Two couplers of the updated design have been tested in LN_2 cryostat from a 135 kW klystron. They were assembled in the cryostat and *in situ* baked to 120°C. That helped to raise the power up to 36 kW CW quite easily. Then very strong vacuum activity forced us to start pulse processing. The couplers were pulse processed up to 85 kW. The total processing time was 15 hrs. After that they were tested in CW mode at 53 kW for several hours. Figures 3 to 7 present plots of RF power, vacuum, and temperatures during that test. Like during prototype coupler tests, we did not see major vacuum actions in cold portion of couplers.

Then the cryostat was warmed up to room temperature and the couplers were exposed to air for four hours, pumped down, and cooled down again. We found out that the couplers still kept the memory about previous processing. We raised the power to 61 kW CW with only short vacuum actions at 55 kW and 61 kW levels.

Meanwhile, the prototype couplers were used for an injector cavity tests in a prototype horizontal test cryostat. With no beam loading, they operated in standing wave mode with full reflection. During that test, the forward power reached 13 kW CW (26 kW average power, 52 kW at peak locations).

CONCLUSION

We have tested four couplers, designed for ERL injector cavities [4] using a liquid nitrogen cryostat.

The test of the prototype couplers revealed weak points of the design, which has been improved. The test also gave a very good experience of handling and assembling couplers in environment close to the one of the real ERL cryostat. The prototype couplers were used later in the horizontal cryostat test of the first ERL Injector cavity.

The modified production couplers showed stable operation and reasonable heating. The test showed they meet requirements and can operate in Cornell ERL Injector.

Due to very tight ERL injector installation schedule, we will not test other couplers separately from the Injector Cryomodule.

REFERENCES

[1] I. Bazarov and C. Sinclair, "High Brightness, High Current Injector Design for the Cornell ERL Prototype," *Proc. of the 2003 Part. Accel. Conf.*, (Portland, OR), p. 2062.

[3] V. Veshcherevich, et al. "Design of High Power Input Coupler for Cornell ERL Injector Cavities", *Proceedings of the 12th International Workshop on RF Superconductivity* (Ithaca, NY), p. 590.

[2] B. Dwersteg, et al., "TESLA RF Power Couplers Development at DESY". *Proc. of the 10th Workshop on RF Superconductivity*, Tsukuba, Japan, 2001.

[4] V. Veshcherevich, et al. "High Power Tests of First Input Couplers for Cornell ERL Injector Cavities", *Proc. of the 2007 Part. Accel. Conf.*, (Albuquerque, MN), p. 2355.