HIGH POWER TESTS OF FIRST INPUT COUPLERS FOR CORNELL ERL INJECTOR CAVITIES*

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Abstract

First two RF power couplers for the ERL injector, currently under construction at Cornell University, have been fabricated. The couplers were assembled in the liquid nitrogen cryostat, built for their tests. A 15 kW CW IOT transmitter was available for coupler tests. A resonant ring was used for additional increase of the power. The couplers were successfully tested up to the goal power level of 50 kW CW. 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.

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.

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.

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

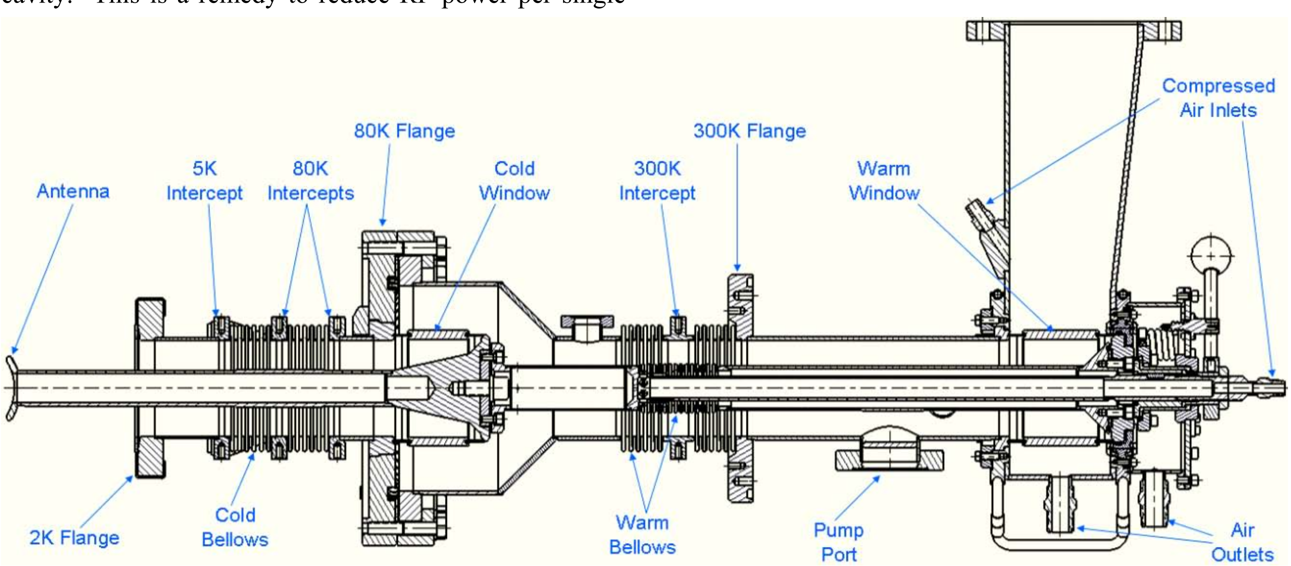

Figure 1: 2D section view of the injector cavity coupler.

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Table 1: Parameters of Couplers

Central frequency	1300 MHz
Bandwidth	±10 MHz
Maximum RF power transferred to matched load	75 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

Twelve couplers have been ordered from CPI/Beverly. Two prototype couplers were manufactured and tested last 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.

Prior to the test, both 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.

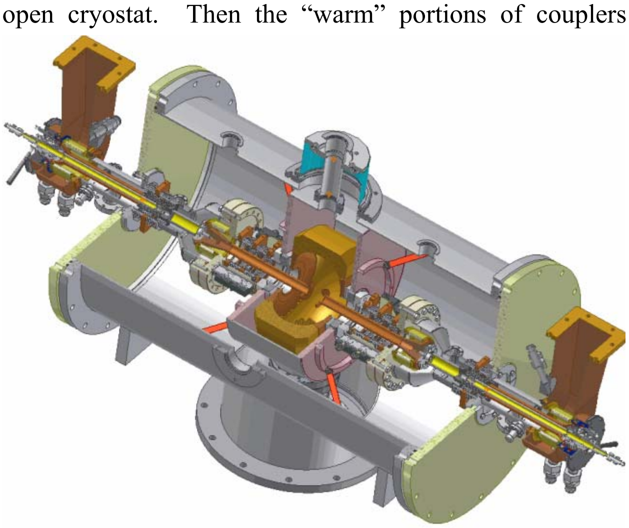

Figure 2: Nitrogen cryostat assembled with coupling cavity and two couplers.

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

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

A high power klystron was not available in time for the coupler test, therefore we used a 16 kW CW IOT transmitter (made by Thales).

The first phase of the test was performed in a "straight-ahead" configuration (November 15–17, 2006). We could easily reach a power level of 15 kW CW after fast processing. No significant vacuum activity was observed.

However, this power level was far from the design value. Therefore, we built a resonant ring, in which the coupler string was inserted. The resonant ring had a gain of 15 dB and we were able to continue coupler testing at higher power. A three-stub tuner was used for ring tuning.

The goal for the second phase of the test (November 27 – December 7, 2006) was to reach 50 kW CW (the power we will need during the operation of the injector).

We had some difficulty with processing above 20 kW 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) 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 e quilibrium after staying several hours at 35 kW.

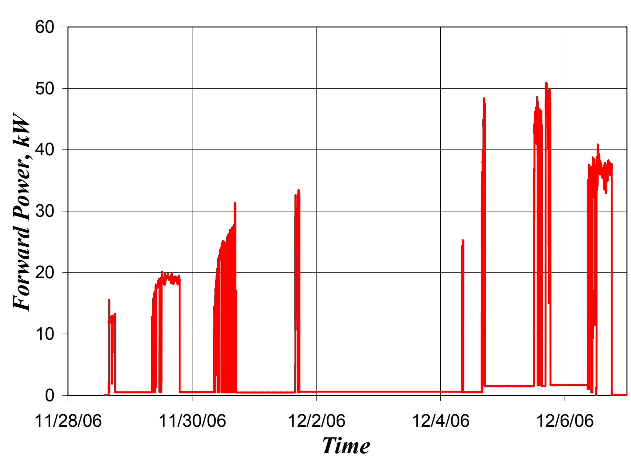

Figure 3: CW power delivered to couplers during the test.

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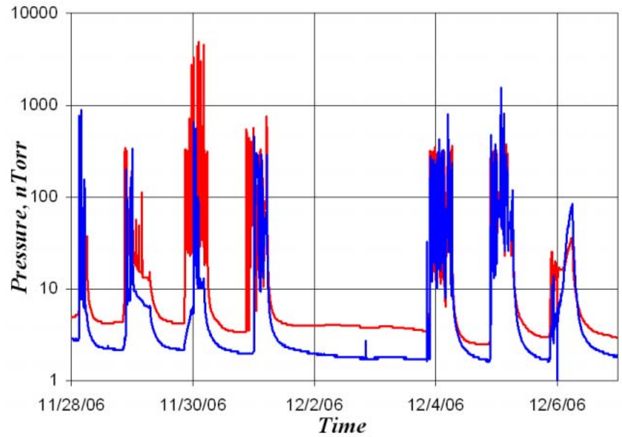

Figure 4: Vacuum in "warm" portion of couplers during the test.

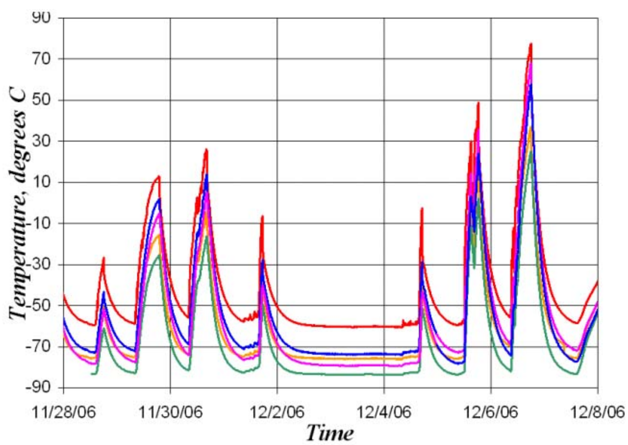

Figure 5: Temperatures of some spots of outer tube in "warm" portion of couplers during the test.

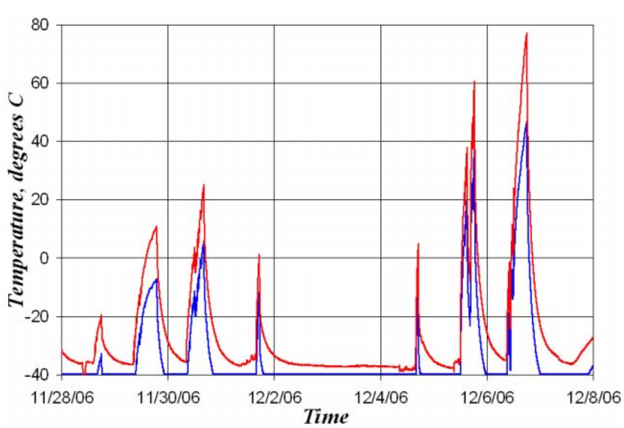

Figure 6: Temperatures of inner tube near the bellows in "warm" portion of couplers during the test.

Measured time constant was of 3 to 5 hrs. Figures 3 to 6 show RF power (excluding pulse processing), vacuum and temperatures during the test.

Thermal analysis confirmed very long thermal time constant and revealed a possibility of thermal run-away. Therefore, we had to do design changes, 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 which exceeded 40°C at 35 kW.

We have ordered ten more couplers of the updated design. The first production pair of couplers will be delivered in June and tested shortly. We now have operating high power klystrons, and one of them will be used for coupler tests.

CONCLUSION

We have tested two prototype couplers, designed for ERL injector cavities, using a liquid nitrogen cryostat. The test revealed week points of coupler design, which have 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 will be used soon in the horizontal cryostat test of the first ERL Injector cavity.

The ERL injector installation schedule is very tight; therefore we plan to do full testing of only the first two new couplers. As we have observed very little vacuum action in the cold portions of couplers, which were vacuum baked, and a lot of vacuum activity in the warm portions, we think that it is very important to implement *in situ* vacuum bake, especially if we are to skip high power testing of input couplers. All input couplers will be *in situ* vacuum baked upon installation in the cryomodule and kept under vacuum after that.

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