OVERVIEW OF CW INPUT COUPLERS FOR ERL

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Abstract

Various efforts for SRF R&D are in progress all over the world for ERL construction. CW (Continuous-wave) input coupler development is one of the key issues for realizing the stable ERL operation. For injector, high power handling is necessary to feed the CW RF power to continuous high current beam acceleration. Furthermore, the soft injector beam should not be disturbed by coupler kick. Thanks to energy recovery, a little power is needed for main linac. However, this feeding average power is also higher than that of the pulsed operation like XFEL or ILC to keep the accelerating field stable under the microphonics of cyromodule. Therefore, it is important for both coupler cases, not to leak the large heat load to He temperature and to avoid the continuous multipacting barriers. In addition, variable coupling is desirable for several beam operations. As a result, many new coupler designs were proposed and developed until now. In this paper, we present the various options and technical issues of ERL input coupler for both injector and main linac. Then we review existing designs associated with R&D testing and summarize the experience and progress in each laboratory around the world.

INTRODUCTION

General Aspects of Input Coupler for SRF Cavity

The input coupler is one of the important components of the cryomodule for operating superconducting cavity. Its design and property affect the cavity performance, beam dynamics, cryogenic system. Furthermore, its designing strategy also determines the overall of the cost of the project, in which the beam line are dominated by the superconducting cavities like XFEL, ILC & ERL. In general, there are several main roles of the RF coupler to operate the superconducting cavity.

1. RF input coupler is a passive deice, which is able to transfer RF Power from RF source to beam loaded cavity optimised reflection.
2. An input coupler works as a transmission line, with a coaxial or waveguide shape, and separate between the atmosphere and vacuum by RF window.
3. The input coupler must prevent the large heat leak from the outside of vacuum insulator at room temperature to cryogenic temperatures (2 to 4.5K). If the high power will be applied to the superconducting cavity, the careful RF and thermal simulation are needed not to add the large heat load, which come from not only the static loss but also dynamic loss caused by RF power feeding, to cryomodule temperatures.
4. For the different operation modes, an adjustable coupling will be required. One method is setting the three stab tuner of the upside of the RF transmission line. If the coaxial coupler is selected, a variable coupling can be done by directly changing the antenna position.
5. The perturbation of the cavity field caused by the input coupler should be minimized not to kick the beam.

In addition, to keep the quality of cavity performance, the following properties are to be cared in designing and testing the input coupler.

6. The mutipacting phenomenon and condition should be considered for the designing of the input coupler.
7. Input coupler should be performed in the clean cyomodule assembly procedures to minimize the risk of the contamination to the superconducting cavities. If many cyromodule assemblies are needed, two RF windows, cold and warm, are better to apply for the input coupler, especially for aiming to achieve the high accelerating field.
8. It is important to reduce the RF processing time. The sophisticated processing procedure and assembly are required to the input coupler.
9. Input coupler should be designed with the mechanical flexibility by considering the mechanical shrinkage under cooling.

Properties of Input Coupler for ERL

ERL consists of the DC or SRF gun, injector, merger, main linac with energy recovery, return loop and beam dump. In order to accelerating the beam continuously, superconducting cavity are needed at injector part and main linac parts. Especially ERL beam current is designed more than 100mA CW beam current.

In injector part including SRF gun, the beam is accelerated at least 5MeV and more. For injector, therefore, high power handling is necessary to feed the CW RF power to continuous high current beam acceleration. For example, we assume that the 2 cell 5 cavities with double input coupler accelerate up to 5MeV, whose condition is same as the parameters of the Cornell injector [1]. One coupler needs to feed at least 50kW RF power. If the number of cavities is decreased to shorten the injector part, a couple must be fed by higher RF power. It is the most challenging issues for the input coupler of injector parts of ERL. Furthermore, the soft injector beam should not be disturbed by coupler kick; the beam energy of injector is very low. In this case, the perturbation of the cavity field caused by the input

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coupler should be minimized not to kick the beam larger, as we have already mentioned in the previous paragraph. Double couplers set in symmetry and the compensating stab are desirable to the beam operation at injector parts.

On the other hand, in main linac, the input power is very small compared with the injector, by the mechanism of energy recovery. Therefore, the coupling is very weak. This results in the small perturbation to the beam. However, this coupling is perfectly not matched to the unloaded Q-value of the superconducting cavity like $1x10^{10}$. The minimum input power will be restricted by the cavity detuning due to the microphonics from the cryomodule itself.

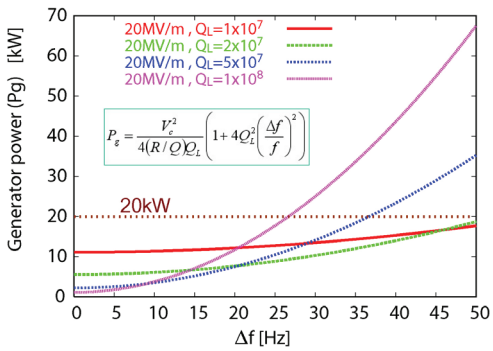

Figure 1: Δf vs input power on several Q_L's.

Fig.1 shows the example of the relation between the cavity detuning (Δf) and the input power corresponding to the several loaded Q-values (Q_L) of accelerating field of 20 MV/m for KEK-ERL 9-cell cavity[2]. If we assume the cavity detuning of Δf=50Hz, which is larger detuning case compared to averaged value of Δf=20Hz, the input power of 20 kW is required under $Q_L=2x10^7$ to minimize all over the detuning rage of Δf=50Hz. This feeding average power is not higher than that of injector but higher than that of the pulsed operation like XFEL or ILC to keep the accelerating field stable under the large microphonics condition. However, the smaller is the detuning range caused by microphonics, the smaller RF power, less than 5 kW, is achieved and the more simple the input coupler is. If the microphonics will be reduced smaller by the sophisticated feedback control and hermetical cryomodule, that also reduces the difficult treatment and cost of the input coupler for the main linac and RF source.

Selection of Coupler Type

Many new coupler designs were proposed and developed until now [3][4]. Table.1 shows the parameters of input coupler for planning to construct and testing at CW ERL, while the table do not include all existing input couplers. The input couplers of table.1 are categorized by main three types. First is the waveguide coupler, which is successfully operated on CESR with the beam current of 0.8A and the RF frequency of 500MHz [5], CEBAF [6] and JLAB-FEL[7] as listed in Table.1. Second is the coaxial coupler with cylindrical ceramic windows. This type of coupler is based on TTF-III coupler[8] and is also modified to apply CW operation at Cornell Univ.[9] and HZB[10] for ERL. Third is the coaxial coupler with disk ceramic windows. This type of coupler was developed and utilized for TRISTAN at KEK[11] and successfully applied to KEKB [12] for high current beam operation of more than 1A with the RF frequency of 508MHz. For ERL, this type of input coupler also applied and developed for the injector[13] and main linac[14] with RF frequency of 1.3GHz for Compact ERL (cERL) [15] and for BNL-ERL[16] with RF frequency of 704 MHz .

Figures of merits and demerits of these types of couplers are expressed in Ref.[17] in detail. We note that these coupler developments are based on the many historical accumulated experiences of designing, fabrication, RF

Table 1: Parameters of present testing or operating input coupler for CW ERL

Facility	Frequency	Coupler type	RF window	Q_{ext}	Max. Power (CW)	Comments
Cornell ERL injector	1300MHz	Coax. Variable	Cylindrical (warm&cold)	$4.3x10^4$-$1x10^6$ (+-9mm)	Test: 60kW (TW) Oper: 30kW(SW)	
KEK-cERL injector	1300MHz	Coax. Fixed	Disk, coax. (warm)	(ini.) 1&$4x10^6$ (final) $1.7x10^6$	Test: 50kW	Travelling wave
KEK-cERL main linc	1300MHz	Coax. Variable	Disk, coax. (warm&cold)	$1x10^7$-$4x10^7$ (+-5mm)	Test : 25kW	Standing wave
BNL-ERL main linac	704MHz	Coax. Fixed	Disk, coax. (warm)	$3x10^7$	Test :50kW	Standing wave
HZB main linac	1300MHz	Coax. Variable	Cylindrical (warm&cold)	$2x10^6$-$2x10^8$	Test: 8kW (SW) 10kW (TW)	Horizontal test
JLAB FEL	1497MHz	Waveguide Fixed	Waveguide planner	$2x10^6$	Test: 60kW Oper: 35kW	Travelling wave

processing, assembly for cryomodule and beam operation. Here, we will review only most recent development of input coupler for ERL.

DEVELOPMENT OF INPUT COUPLER FOR ERL INJECTOR

Cornell ERL Injector Input Coupler

Fig.2 shows the schematic design of the Cornell ERL injector coupler. This coupler is based on the TTF-III input coupler. In order to apply the high power CW RF feeding, the following modifications are applied.

- Change impedance from 70 Ω to 60 Ω.
- Make strong coupling by enlarging antenna.
- Forced air cooling was applied to inner conductor and warm window.
- The outer conductor bellows has many optimized thermal anchor to reduce the heat load leakage to 2K.

In high power test stand under liquid nitrogen cooling with coupling cavity, this prototype input coupler was successfully kept at 61 kW CW in travelling wave. Cornell ERL injector cryomodule of 5 cavities was already assembled by using 10 these input couplers. And until now, the beam operation with maximum beam current of 25mA was successfully carried out at Cornell ERL injector test stand [18]. This coupler will be used in the CW ERL cryomodule development collaborated with Daresbury, Cornell, LBNL, Rossendorf and Stanford [19].

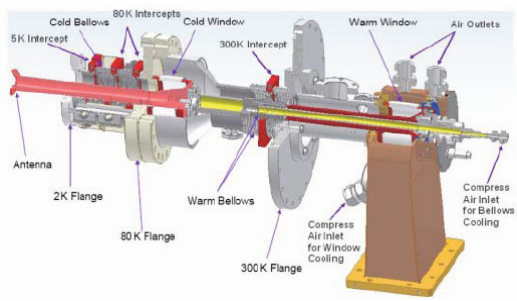

Figure 2: Cornell ERL injector input coupler.

KEK-cERL Injector Input Coupler

The Compact ERL injector cryomodule has three 1.3GHz 2-cells cavities driven by a pair of coaxial coupler with a warm TRISTAN type ceramic window aiming to carry each 170kW for 100mA beam operation. Fig.3 shows the input coupler for KEK-cERL injector. The window and antenna are cooled by water, the 5K and 80K thermal anchors without bellows are used. Prototypes of injector coupler of cERL have been conditioned at high power test stand by using 300 kW CW klystron as shown in the top of Fig.4. The bottom of Fig.4 shows the results of the conditioning at this test stand.

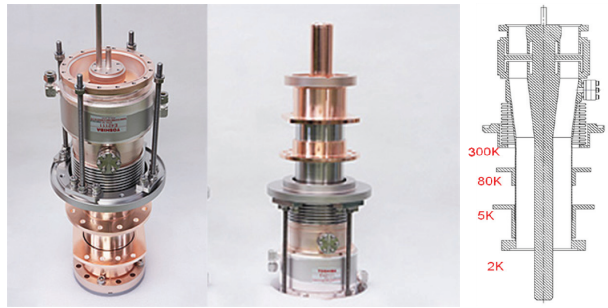

Figure 3: KEK-cERL injector input coupler.

120kW RF power was successfully fed in pulse processing mode with 10% duty. In CW power feeding, we successfully kept the 50 kW RF power for 0.5 hours and the 30 kW RF power for 1.5 hours. Unfortunately, the input coupler only kept for 1 min. under 100kW CW RF power feeding caused by the doorknob arcing and heating of the inner conductor, where the water did not cool. We mention that this coupler satisfy the initial requirements of cERL of 10mA beam operation from this high power test. However, we need to modify the design of input coupler, especially cooling inside of the inner conductor, to achieve the beam operation up to 100mA, which is a final goal of cERL,.

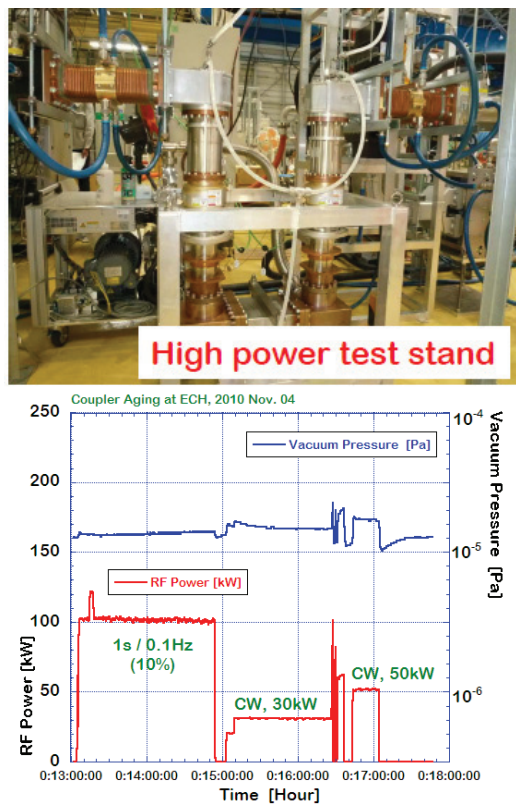

Figure 4: (top) high power test stand, (bottom) results of coupler processing at test stand.

DEVELOPMENT OF INPUT COUPLER FOR ERL MAIN LINAC

KEK-cERL Main Linac Input Coupler

The 1.3 GHz input coupler for ERL main linac was also developed in KEK[2]. This coupler is based on the STF baseline cavity, which cavity also utilized TRISTAN type coaxial coupler with disk ceramic window [20]. For ERL operation of more than 20 kW RF power with standing wave, the following modifications were made:

- The impedance was changed from 50 Ω to 60 Ω.
- Ceramics were changed from 95% to 99.7 % alumina.
- Gas cooling was applied to inner conductor.
- Variable coupling was added near the cold window to change the loaded Q corresponds to the amplitude of the microphonics and various beam operations.

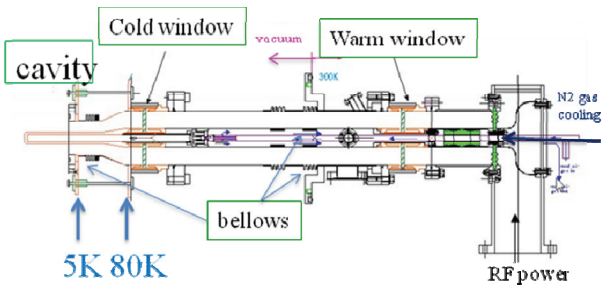

Figure 5: KEK-cERL input coupler for main linac.

Recently, the high power test was done under liquid nitrogen cooling in the vacuum insulator by fabricating the prototype of input coupler for main linac of cERL as shown in Fig.5[14]. This prototype input coupler successfully increased the RF power up to 25kW with standing wave, limited by RF power source of IOT. This coupler also kept the required 20 kW RF power for 16 hours stable in standing wave condition. Now, we will fabricate two input couplers for the cERL main linac cryomodule assembly.

BNL-ERL Main Linac Input Coupler

The input coupler for ERL main linac is developed at BNL. Fig.6 shows the design of the BNL input coupler based on the SNS coupler [21], which used the TRISTAN-type coaxial coupler with a warm disk ceramic window. The frequency was modified to 704MHz. Inner conductor is cooled by water and outer conductor is cooled by liquid He. The prototype of input coupler was already fabricated and tested in cryomodule up to 50kW in standing wave[16].

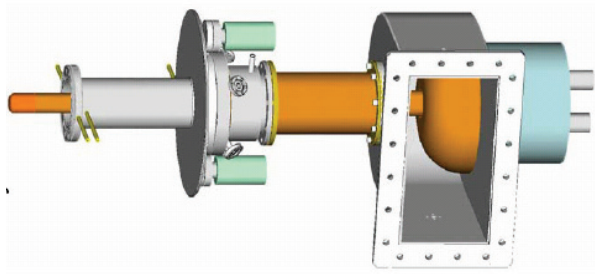

Figure 6: BNL-ERL main linac input coupler.

Main Linac Input Coupler Development at HZB

Recently, HZB (previously BESSY) started ERL R&D for constructing BERLinPro to demonstrate the high current ERL[22]. For several years, however, the extensive studies in HoBiCaT at HZB have already served to adapt TESLA technology including TTF-III coupler to CW operation by using the horizontal test stand. Fig.7 shows the schematic drawing of the TTF-III coupler applying to CW operation. The air cooling of inner conductor is a clear difference with pulsed operation. In this horizontal test, RF input power of 8kW with standing wave could feed to this coupler. By assuming the slope of the temperature rise of mainly inner conductor, we will expect to extrapolate feeding the RF power up to 20kW.

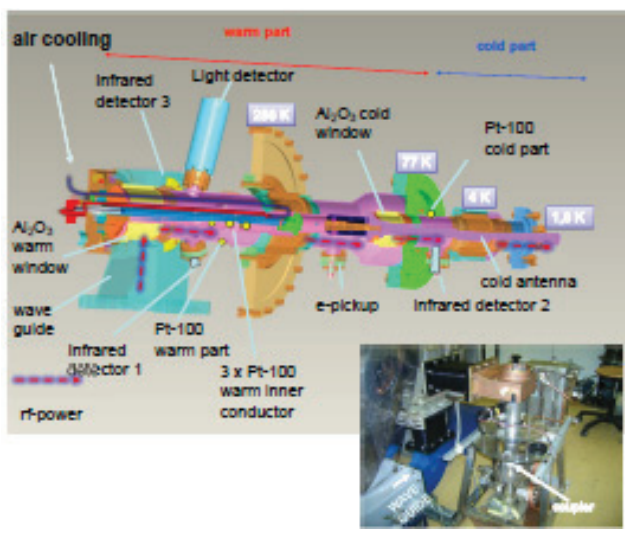

Figure 7: TTF-III coupler test for CW operation at HZB.

Another important test is how much the microphonics will be reduced under ERL operation. In this test stand, by using feedback and feed forward schemes with a fast piezo tuner, the fluctuation of microphonics can be suppressed from 12 Hz to 3 Hz of peak-to-peak values [10]. In main linac, the lower power of less than only a few kW can be achieved for ERL operation by using these feedback and feed forward scheme.

SUMMARY

Recent R&Ds of input couplers reviews only associated with CW ERL. Many couplers have been designed for different ERL cryomodules. Coupler designs were based on successful existing designs (TTF-III, TRISTAN coupler, waveguide) though often with necessary upgrades or modifications. Requirements for injector couplers are challenging due to high power that must be delivered to the intense beam. Couplers for main linacs are dominated by microphinics of cryomodule. Reduction microphinics makes the coupler handling easier and the total cost more efficient. To straggle with these issues, various R&D for ERL input coupler for CW operation are in progress mainly at Cornell Univ., KEK, BNL, JLAB, Daresbury and HZB.

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