ADVANCES AND PERFORMANCE OF INPUT COUPLERS AT KEK

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Abstract

Activities on high power input couplers at KEK are reported. High power performances of the STF-I input couplers in the STF phase-1 and conditioning results of the TTF-V input couplers delivered from LAL are presented. Current developing status of the STF-II input couplers for the S1-Global and the cw input couplers for the cERL injector cryomodule is described.

INTRODUCTION

High power performance of input couplers is crucial to achieve a stable operation at high accelerating gradients or high beam currents in a superconducting cavity system. An rf window for transferring rf power and maintaining a vacuum is a key component in a high power input coupler. A coaxial disk rf window with a choke structure was initially developed for the 508 MHz Tristan input couplers [1] and was applied to the KEKB input couplers in later years [2]. The Tristan/KEKB input couplers were used for superconducting cavities operating in cw mode. The same type of a coaxial disk rf window has been also applied to the 805 MHz SNS input couplers at ORNL [3] and the 972 MHz ADS input couplers at JAEA/KEK [4] in a pulsed operation. In the SNS and ADS input couplers which have only one warm rf window, the high power performance up to 2 MW in a pulsed operation with high duty factors had been already successfully demonstrated at the test stand, [3, 4]. The 1.3 GHz STF-I input couplers [5] with a cold and a warm coaxial disk rf window have been developed for the STF (Superconducting rf Test Facility) cryomodule, which includes four Tesla-like 9-cell cavities in the STF phase-1. High power tests of the STF cryomodule equipped with four STF-I input couplers had been carried out in 2008, [6]. Other similar input couplers, like the STF-II input coupler for the S1-Global cryomodule and the cw input coupler for cERL injector cryomodule are under development at KEK.

On the other hand, the TTF-III input coupler [7] for FLASH/XFEL at DESY has two cylindrical ceramics rf windows. The TTF-V input coupler [8] was originally designed at DESY and has an enlarged structure of the TTF-III coupler to increase high rf power capability. Four TTF-V couplers were fabricated at LAL-Orsay in addition with some mechanical modifications. Two of four TTF-V input couplers had been successfully processed at LAL [9]. Two TTF-V couplers were delivered to KEK under the FJPPL collaboration [10] in order to carry out conditioning with much higher rf power level at KEK.

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COUPLER ACTIVITIES

Current activities of input couplers at KEK are summarized as follows:

- The STF-I input couplers used in the cryomodule tests called the STF phase-1.
- The TTF-V input couplers from LAL
- The STF-II input couplers to be used for the S1-Global cryomodule.
- The cw input couplers for the cERL injector cryomodule.

Schematic drawings of the STF-I coupler and the TTF-V coupler are shown in Figure 1. The type of the rf window is different in each other; one is a coaxial disk ceramics and another is a cylindrical ceramics. However, they have a very similar structure, like a diameter of the input port (60 and 62 mm), a fixed coupling without bellows, and an rf characteristic impedance of a coaxial line of 50 Ω.

The input rf power levels required for XFEL and ILC are listed in Table 1. Conditioning at the test stand is carried out under the matching condition terminated at a dummy load. Conditioning in the cryomodule at room temperature is carried out under the total reflection condition reflected at a cavity. Conditioning of the TTF-III input couplers has been routinely carried out up to 1.0 MW at the test stand and 250 kW in the cryomodule, [11]. The conditioning power level for ILC is required up to 2.0 MW at the test stand and 500 kW in the cryomodule in a pulsed operation (0.5 msec), in order to transfer rf power of 350 kW in a beam operation at 31.5 MV/m. The rf power level for conditioning is twice higher than that for XFEL.

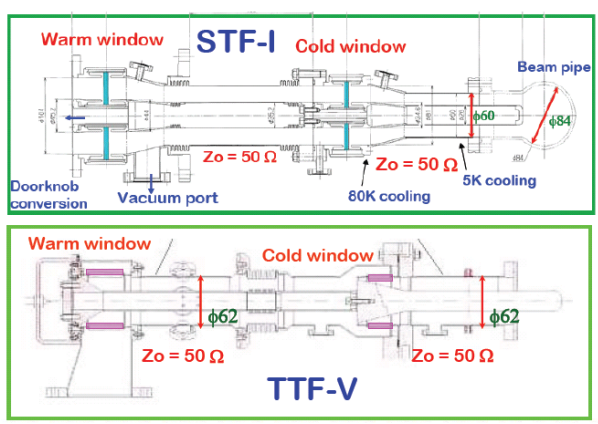

Figure 1: Schematic drawings of an STF-I input coupler (top) and a TTF-V input coupler (bottom).

Table 1: Input rf power required for XFEL and ILC

XFEL : TTF-III input coupler

Conditioning	RF Power	Operation
Test stand	1.0 MW/ 0.5 MW	0.4 ms/ 1.3 ms
Cryomodule	250 kW/ 125 kW	0.4 ms/ 1.3 ms
Beam operation	125 kW	23.6 MV/m

ILC : STF-I, II input coupler, TTF-V input coupler

Conditioning	RF Power	Operation
Test stand	2.0 MW/ 1.0 MW	0.5 ms/ 1.6 ms
Cryomodule	500 kW/ 250 kW	0.5 ms/ 1.6 ms
Beam operation	350 kW	31.5 MV/m

STF-I INPUT COUPLER

Tristan-type coaxial disk rf window with a choke structure [1] is used for a cold and a warm part of the STF-I input couplers. Ceramics disks are made of Al_2O_3 with the purity of 95%, (HA95 from NTK). The disk sizes of a cold and a warm rf window are 6.2 and 6.6 mm in the thickness, 92 and 116 mm in the outer diameter, respectively. Thermal shock tests of the ceramics disks were repeatedly carried out by liquid nitrogen. After this, coating with TiN on the surface of the vacuum side was performed, and the thickness of the deposited layer is about 10 nm. First brazing for fabricating rf windows was carried out at about 1000 °C in a hydrogen furnace. The second step of the brazing procedure is the joining of rf windows and coaxial parts which consist of an inner conductor (antenna) and an outer conductor. The coaxial parts are made of stainless steel, and copper plating of 30 µm on the rf surface was carried out, except an outer conductor of a cold part (< 5 µm) to reduce heat losses at 2 K. The completed STF-I input couplers after the second brazing at about 800 °C are shown in Figure 2.

Prior to assemble with 9-cell cavities, conditioning of the input couplers was carried out at a high power test stand with a pulsed klystron of 5 MW, as sown in Figure 3. Conditioning was initially started in a short pulse operation of 10 or 100 µsec, and rf power level was increased very carefully. Finally, conditioning up to 1.0 MW in a pulsed operation with 1.5 msec and 5 Hz was successfully performed in four input couplers. The conditioning time at the test stand was about 50 hours, as shown in Figure 4.

After installation of the cryomodule in the STF tunnel as shown Figure 5, connection of a warm coupler with a cold coupler was carried out in a working area covered with a special clean booth to keep a clean environment. In-situ baking of cold rf windows inside the cryomodule was carried out at 85°C for 15 hours. Baking of the cold rf windows prior to conditioning is very effective to reduce the conditioning time. Conditioning of the input couplers at room temperature before cool-down was carried out up to 240-330 kW under the total reflection condition. The conditioning time was 11-17 hours, as shown in Figure 6.

Figure 2: The STF-I input couplers with a fixed coupling.

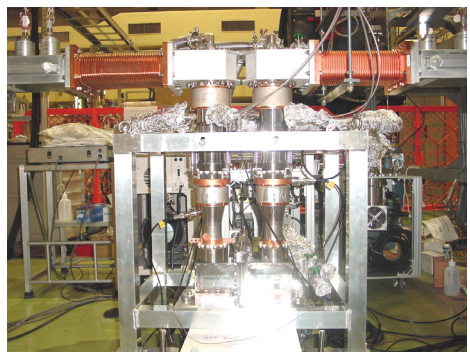

Figure 3: Set-up of the high power test stand.

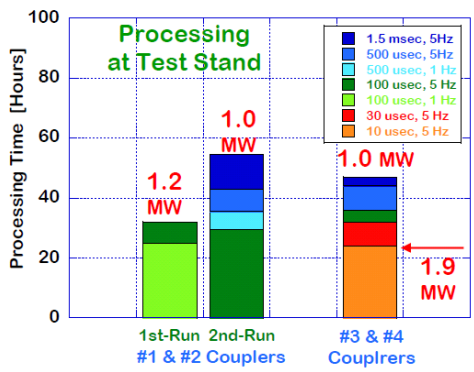

Figure 4: Conditioning time of two pairs of input couplers at the test stand under the matching condition.

Conditioning of the No.3 coupler (C/#2 cavity) was carried out twice, and the conditioning time in the second was remarkably short. It is considered that a memory of the previous conditioning has been preserved.

After the cryomodule was cooled down at 2 K, the input rf power of 200~360 kW was successfully transferred into four cavities to achieve the high accelerating gradients at 25~34 MV/m in a short pulse operation with 0.6 msec and 5 Hz, [6]. Trial to check the limitation of the power capability of the STF-I input

couplers was carried out at room temperature, after all of the cryomodule tests at 2 K had been finished. The maximum input rf power of 625 kW in a pulsed operation with 1.5 msec and 5 Hz was attained through the conditioning for several hours. The limitation was caused by discharge around the high power rf distribution system like a circulator or a power divider, not at the input coupler itself. Achievement of the input rf power of 625 kW is very encouraged for the target in ILC.

Figure 5: Installation of the cryomodule in the STF tunnel. Four input couplers were connected with the high power rf distribution system.

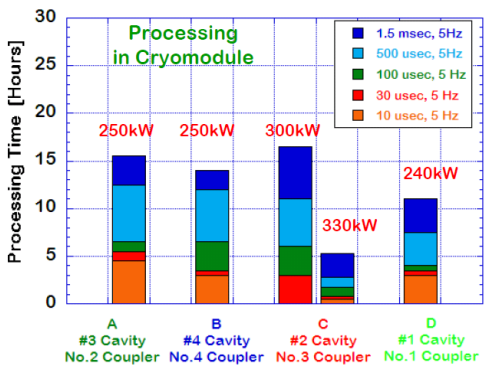

Figure 6: Conditioning time of four input couplers in the cryomodule under the total reflection condition.

TTF-V COUPLER

Main purpose of the FJPPL collaboration work [10] is to perform conditioning with a higher power level by using the high power rf system with a 5 MW pulsed klystron at KEK. Assembly of the TTF-V couplers shown in Figure 7 and 8 was carried out in a clean room at LAL. The TTF-V couplers (#3 and #4) were packed in a special box, and were transported to KEK. After arriving at KEK in January 2009, vacuum valves, vacuum gauges and viewing windows for arc sensors were attached with the couplers in a clean room. The TTF-V couplers were installed in the test stand at STF, and were baked at 130 ^{o}C for 60 hours. Then, the waveguide transitions were installed in the cylindrical ceramics, and were connected with the high power rf system.

Figure 7: The TTF-V input coupler from LAL-Orsay.

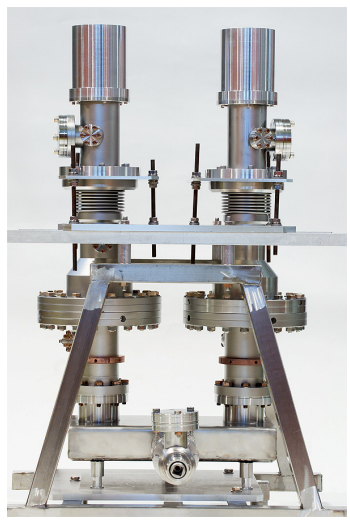

Figure 8: The TTF-V input couplers. The original rf design was carried out by DESY, the mechanical design was done by LAL-Orsay, and these couplers were fabricate by RI (Research Instruments, Germany).

Conditioning of the TTF-V input couplers were carried out in three steps as follows:

- Step 1 is the same conditioning procedure as the TTF-III couplers for FLASH/XFEL;
  1.0 MW (< 400 μsec) and 500 kW (1.3 msec), 5 Hz.
- Step 2 is the required power level for ILC;
  2.0 MW (< 500 μsec), 5 Hz.
- Step 3 is the required power level for ILC;
  1.0 MW (1.5 msec), 5 Hz.

Conditioning was started in a short pulsed operation with 20 μsec and 5 Hz, and rf power was increased very carefully. The interlock level of the vacuum pressure observed near the rf windows was set to initially $1x10^{-4}$ Pa, then relaxed a little. After conditioning for 45 hours, the input rf power level reached to 1 MW, and then the pulse width was gradually extended. Finally, the input rf power of 500 kW was achieved in a pulsed operation with 1.5 msec and 5 Hz after conditioning for about 60 hours. This conditioning time was twice longer than that in the #1 and #2 TTF-V input couplers at LAL, [9]. In the step 2, the

input rf power level was increased very smoothly up to 2 MW within the 200 μsec. But, after discharge occurred once in the 400 μsec operation, the conditioning was needed to continue for rather longer time. Finally, it took for about 120 hours to achieve a stable operation at 2 MW with 400 μsec and 5 Hz. In step 3, the target power level of 1 MW in a long pulse operation with 1.5 msec was achieved without any troubles. Therefore, the TTF-V couplers achieved the target input rf power for ILC after total conditioning time for about 200 hours.

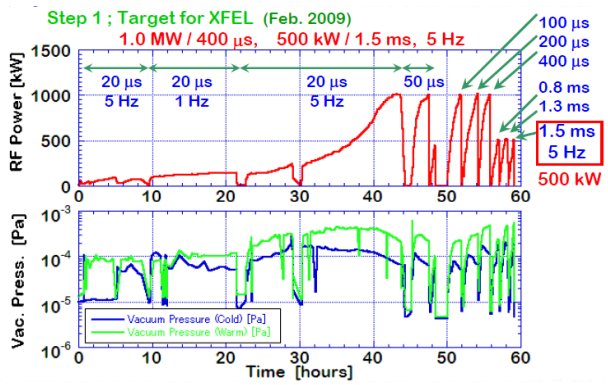

Figure 9: RF conditioning in the first step up to 1 MW (500 kW) in the 400 μsec (1.5 msec) pulsed operation: Time evolution of the input rf power (top) and vacuum pressure (bottom).

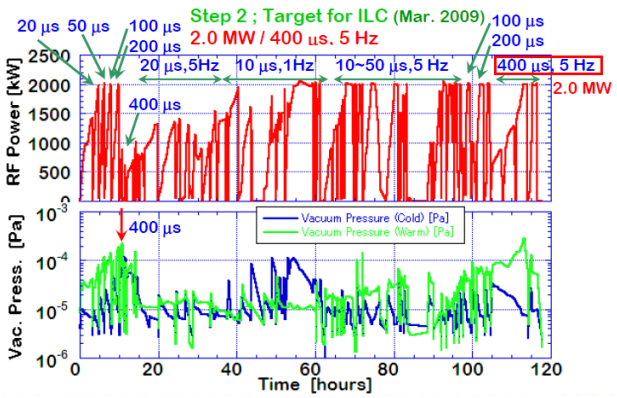

Figure 10: RF conditioning in the second step up to 2 MW in the 400 μsec and 5 Hz pulsed operation.

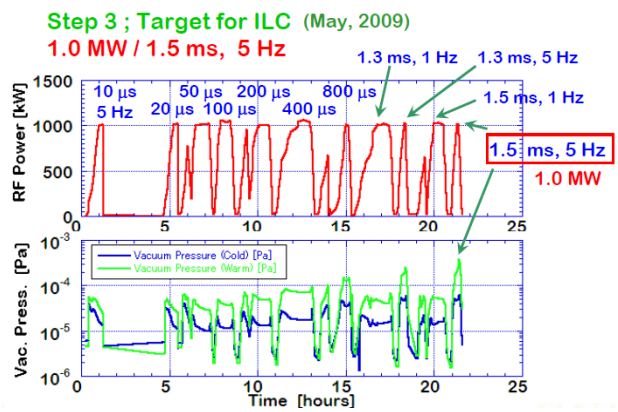

Figure 11: RF conditioning in the third step up to 1 MW in the 1.5 msec and 5 Hz pulsed operation.

STF-II INPUT COUPLER

Several modifications in the STF-II input couplers for S1-Global were made by considering the results of the cryomodule tests in the STF Phase-1, [6]. The schematic drawing and the calculation result by HFSS are shown in Figure 12. Main improvements in the STF-II input couplers are summarised as follows:

- Bellows were attached at the antenna tip of the inner conductor, so that the variable coupling of +/- 30% will be available.
- RF characteristic impedance was changed from 50 Ω to 41.5 Ω, because the diameter of the inner conductor was enlarged in order to insert a mechanism for the variable coupling inside the inner conductor.
- Thermal anchors at 5 K and 80 K were improved to suppress heat losses more efficiently.
- Doorknob transition was modified to the compact size to reduce the total length to connect with a waveguide system.

Two STF-II input couplers have been already completed as shown in Figure 13. Rf conditioning of the STF-II input couplers will be started soon.

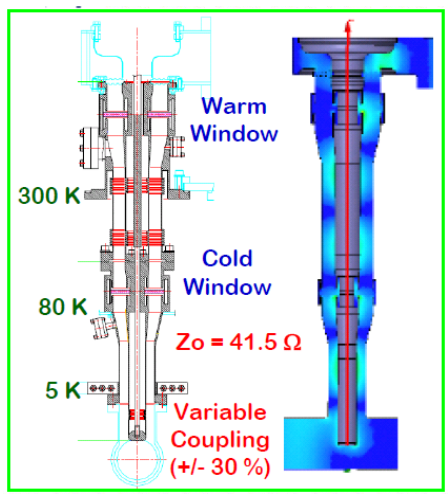

Figure 12: A schematic drawing of the STF-II input coupler (left) and an rf calculation result by HFSS (right).

Figure 13: A set of a cold window part and a warm window part in the completed STF-II input coupler.

INPUT COUPLERS FOR CERL

The cERL injector cryomodule [12, 13] contains three 2-cell cavities as shown in Figure 14, and each 2-cell cavity has two input couplers facing each other. The required rf power is 170 kW per an input coupler in a cw operation at 14.5 MV/m with a beam current of 100 mA, (see, Table 2). This required rf power is very challenging issue for developing this input coupler. The schematic drawing and the calculation result by HFSS are shown in Figure 15. Water cooling channels are installed inside the inner conductor. The static and dynamic thermal losses at 2 K in an input coupler are estimated to be about 2 W and 6 W, respectively. The rf losses at 2 K on a cavity surface are about 6 W, so that total thermal losses at 2 K are estimated to be about 54 W in the cERL injector cryomodule. The cERL injector input couplers have been already completed as shown in Figure 16. The rf conditioning will be carried out in the high power rf system with a cw 300 kW klystron, [14].

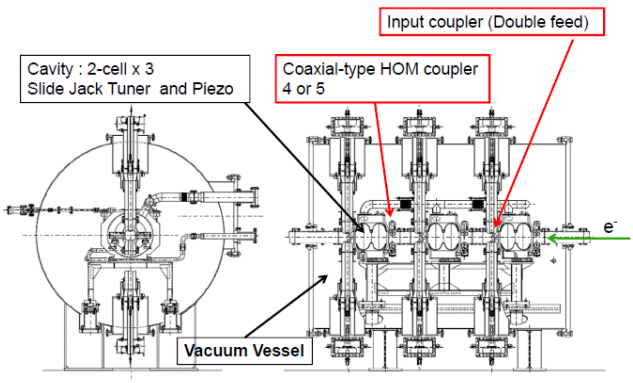

Figure 14: Cryomodule for the compact ERL injector linac. Total six input couplers are installed in the cryomodule.

Table 2: Input rf power required for cERL injector.

cERL : Injector input coupler

Condition	RF Power	Operation
Test stand	200 kW	cw
Cryomodule	50 kW	cw
Beam operation	170 kW	14.5 MV/m

SUMMARY

Advance and performance of the input couplers at KEK were reported in this paper. The current progresses are summarised as follows;

- Conditioning of the STF-1 input coupler up to 625 kW was achieved in the cryomodule at room temperature.
- Conditioning of the TTF-V input couplers up to 2 MW was achieved in the test stand.
- Conditioning of the STF-II input couplers and the cERL injector input couplers will be started soon.

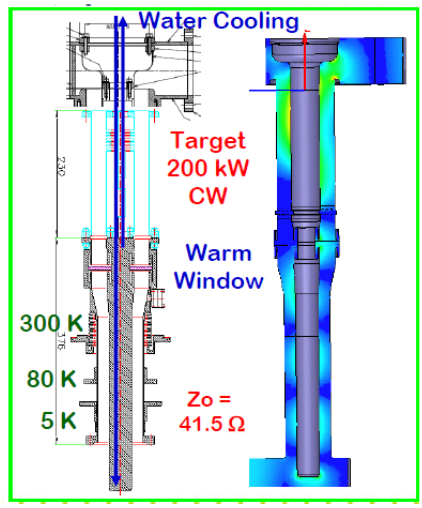

Figure 15: A schematic drawing of the cERL-injector input coupler (left) and an rf calculation result by HFSS (right).

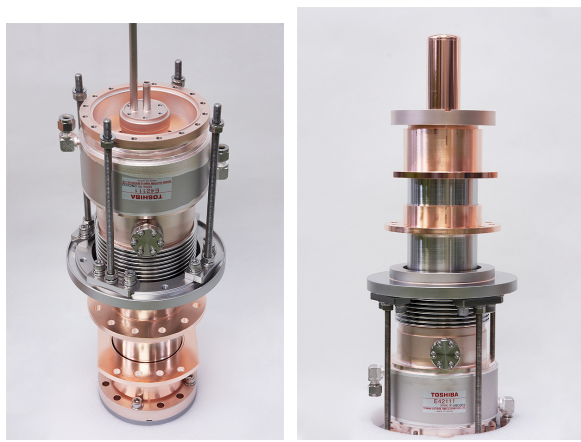

Figure 16: A completed cERL injector input coupler for a cw operation.

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