HIGH POWER RF INPUT COUPLERS AND TEST STAND FOR THE B*ERL*INPRO PROJECT

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Abstract

The bERLinPro project [1], under construction at HZB, is a 100 mA, 50 MeV superconducting RF (SRF) energy recovery linac (ERL) being built to study the accelerator technology and physics of operating a high current SRF ERL. For this high current operation, coaxial RF power couplers capable of handling 115 kW of power (per coupler, dual couplers per cavity), continuous wave (cw) at 1.3 GHz are required for both the SRF photo injector and booster cavities. In order to sustain this power level a coupler has been designed based on the high power coupler currently in use at the KEK-cERL. Two key changes that were made to the coupler were the modification of the coupler tip, termed a golf-tee, as well as increased cooling of the inner conductor. This former modification is incorporated so as to achieve the desired coupling, Q_{ext}~10^5, with minimal coupler penetration into the beam pipe. Herein, we discuss the RF design and properties of the high-power coaxial coupler for the photo injector as well as booster cavities of bERLinPro, along with the design of the test stand for conditioning a pair of couplers.

INTRODUCTION

In the bERLinPro project [1], a 1.4 cell photo injector cavity delivers a 100 mA, average beam current, at 2.3 MeV [2]. This beam passes through three Cornell type [3] superconducting (SC) cavities (two cells each cavity). The first of the three cavities is an energy chirper, operating at the zero crossing, the other two cavities accelerate the beam from 2.3 MeV to 6.5 MeV. The 6.5 MeV beam is injected in the ERL ring. In the first turn the beam accelerates to 50 MeV using three SC main linac cavities and circulates through the ring. After completing one turn, the beam is passed back through the main linac where it is decelerated 180° out of phase and the beam power is delivered back to the cavities. After delivering the energy back in the cavities the beam is deflected to the 600 kW high power beam dump. The maximum accelerating gradient in the main linac is ~17.8 MV/m [1]. However, as the energy recovery (ER) technique is being relied upon, the input power requirement of the main linac cavities is rather low, about 10 kW cw. For this purpose we utilise the readily available TTF III couplers [4] that were modified by HZB for cw operation [5]. However, in the photo injector as well as booster cavities there is no ER process; hence the power requirement of these cavities is higher by an order of magnitude for the nominal beam operation. For exciting the photo injector as well as booster cavities with high power, we designed a coaxial fundamental power coupler (FPC) referred to as bERLinPro (BP) coupler. The baseline design of the BP coupler is KEK's cERL [6-7] FPC design with two main modifications: (*i*) golf-tee tip [8], so as to enhance the beam-power coupling without inserting the tip of the coupler deeper in the cavity beam pipe and (*ii*) additional cooling of the inner conductor. Modification (*i*) has been completed and (*ii*) is underway. In the following section we discuss the general bERLinPro FPC requirements for several stages of the project. In the penultimate section, we discuss in detail the challenges of designing high power coupler at 115 kW cw power [1,7]. In the last section we summarise our RF study on the design issues and discuss our future steps in order to build and test the BP couplers.

FPCS FOR B*ERL*INPRO

The recirculation of a 100 mA beam current at 50 MeV energy is expected to be demonstrated by the end of December 2018. The project is envisaged in three stages, namely injector0, injector1 and injector2 depending upon the photo injector and beam current. A detailed description of these stages is explained in [1] and is outlined in Table 1 below. The photo injector and booster cavities with FPC are presented in Fig. 1.

Table 1: Phases of the BERLinPro SRF Photoinjector

Parameters	Injector0	Injector1	Injector2
Goal	SRF demo	High brightness	High brightness and high current
Cathode	Pb(SC)	CsK_2Sb(NC)	
Bunch charge	6 pC	77 pC	
I_{avg}	50 nA	5 µA/4mA	100 mA
Power (peak, cw)	10 kW	10 kW	230 kW
Coupler	CW-TTF III	CW-TTF III	cERL → BP

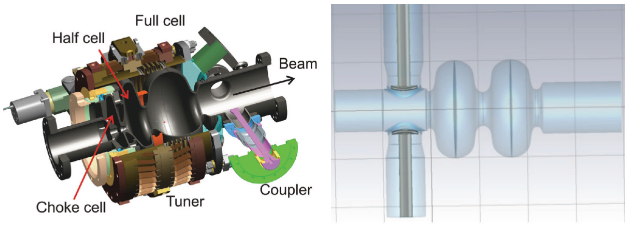

Figure 1: SRF photo injector with TTF III coupler (left) and booster cavity with modified cERL coupler (right).

Due to the low beam current in the first two stages, the power requirement is low ~10 kW. Hence the TTF III power couplers modified for cw operation are going to be used in these stages. As mentioned in the previous section, the main linac will also be employed with the TTF III couplers. For the final stage, the beam current is nominal hence power requirement of the photo injector and booster cavities is high: 230 kW cw (per cavity, delivered via 2 couplers), it is also worth noticing that there is no ER process in these cavities. Hence it is necessary to employ an FPC that can withstand a high power of about 115 kW. The cERL coupler (KEK) is the closest candidate for this purpose. However, the Q_{ext} requirements of bERLinPro are different than that of the cERL, it demands a higher beam-power coupling. A straight forward solution to achieve higher coupling is to insert the coupler tip deeper into the beam tube. However, doing so might lead to problems such as excessive electric field in the vicinity of the coupler tip and possibility of a higher coupler kick. In order to avoid this, we modified the coupler tip to a golf-tee shape [8] which allows us to maintain the required beam-power coupling without inserting the coupler tip deeper inside the beam tube. A schematic of the golf-tee shape is illustrated in Fig. 2.

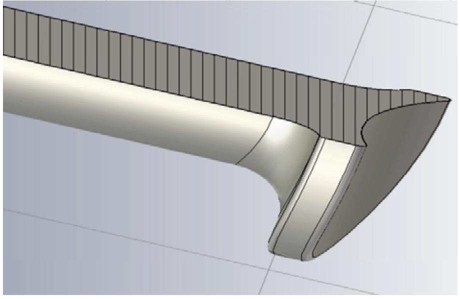

Figure 2: Golf-tee shape of BP coupler tip.

Achieving the required coupling precisely within a given tolerance is an important criterion as the coupler penetration is fixed (unlike TTF III flexible coupling). As the total requirement of the input power per cavity is 230 kW cw, it was decided to use two opposed FPCs so that the power per coupler can be reduced to half. Due to the symmetry, this layout also reduces the coupler kick. Other details of the RF design of the BP FPC are discussed in the next section.

RF DESIGN OF BP COUPLER

For detailed electromagnetic (em) study and RF designing of the FPC, we utilised commercially available codes such as HFSS [9] and CST MWS [10]. The RF design of the BP FPC is presented in Fig. 3. The impedances of the coax line in the cold part (z_0= 66.6 Ω), warm part (z_0= 46.3 Ω) and the taper geometry connecting them were not changed compared to the cERL design [6-7]. However, the inner conductor geometry is made smoother and easy to fabricate by removing the Teflon disc above the RF window. The door knob geometry was designed so as to match the impedance of the coupler with the standard WR650 waveguide at the input end. As the RF window and cold part of the coupler are not changed, the only possible way to tune the coupler to a minimum reflection at the operating frequency is to optimise the width and slanted side of the door knob waveguide. It is observed in the simulations that the reflection (S_{11}) is very sensitive to these parameters. Once the coupler is fabricated, the slanted side is the most important part in the door knob design to tune the frequency [11]. In order to get the reflection below -30 dB (including losses) it was necessary to reduce the width of the waveguide (housing the door knob) to 140 mm from 165.1 mm. Due to this, a ramp was introduced for a smooth transition between the waveguide of the door knob and standard WR650 waveguide at the input end. For the optimised geometry, the S-parameter scan is shown in Fig 4. The S_{11} at the operating frequency is about -35 dB with a narrow bandwidth of ~4 MHz. As the design of the cold part of the coupler along with the RF window are fixed, it is quite challenging to increase the bandwidth beyond the present one by optimising the door knob geometry alone.

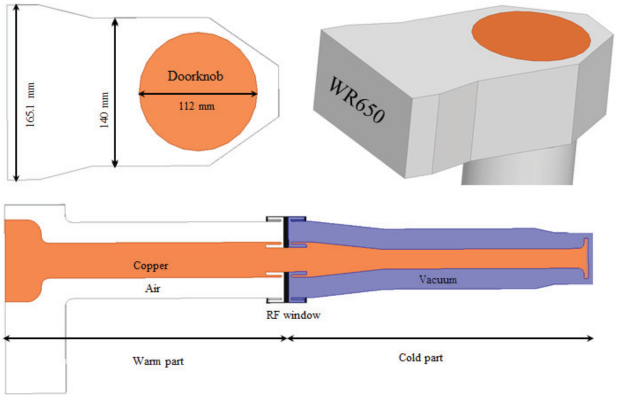

Figure 3: RF model of BP FPC.

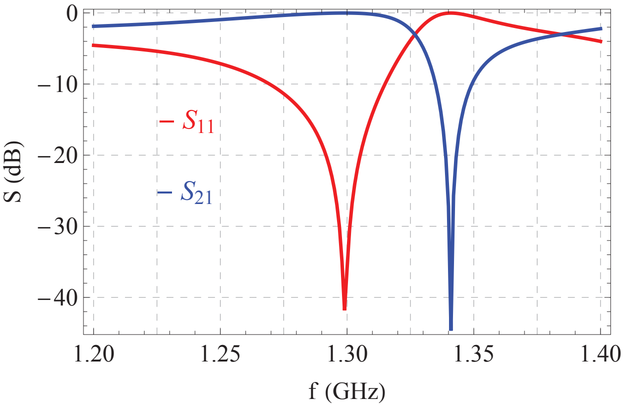

Figure 4: The S parameters of BP FPC.

Though the total power requirement of the cavity is 230 kW, benefitting from the dual couplers per cavity entails 115 kW power per coupler. However, in the worst case scenario if the input power is completely reflected (some mismatch or no beam condition) then the amplitude of the surface E-field might increase up to twice (i.e. Standing Wave condition). In this case, field enhancement may lead to an electrical breakdown. The door knob is operated in air; the breakdown limit of dry air at 1 atm pressure is 3 MV/m. The electric field anywhere in the coupler should not exceed this limit. Fig. 5 shows the worst case electric field in the coupler at various locations at 115 kW power. It is observed that, in the worst case, the electric field in the vicinity of the choke near the window is ~2.44 MV/m, which is within the acceptable limit. Even though the gap between the doorknob and the slanted side is as small as ~8 mm, the worst case scenario field in this region is ~0.9 MV/m.

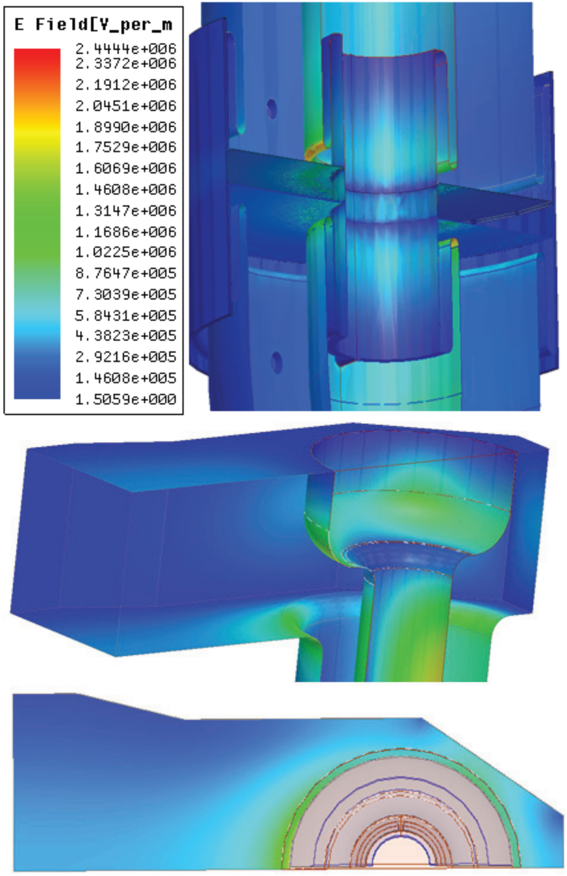

Figure 5: E-field in the worst case of full reflection: choke region (top), door knob (middle) and narrow gap of slanted side of the wave guide (bottom).

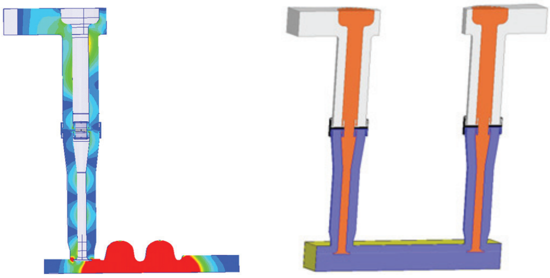

Figure 6: Booster cavity (left) and test stand (right).

The Q_{ext} of the coupler is calculated for the booster linac using the perfectly matched layer (PML) boundary condition in HFSS. The desired $Q_{ext} \sim 1 \times 10^5$ is achieved when the coupler tip is at 41 mm from the electrical centreline of the cavity; this calculation is cross checked with the CST MWS calculations. A pictorial representation of the BP coupler with the booster cavity is shown in Fig. 6 (left). In order to condition a pair of couplers at 115 kW cw power we designed a travelling wave resonator box, and is illustrated in Fig. 6 (right). Figure 7 illustrates the frequency sweep of S parameters. The S_{11} in this case is ~-40 dB (with losses) with a narrow bandwidth of 4 MHz.

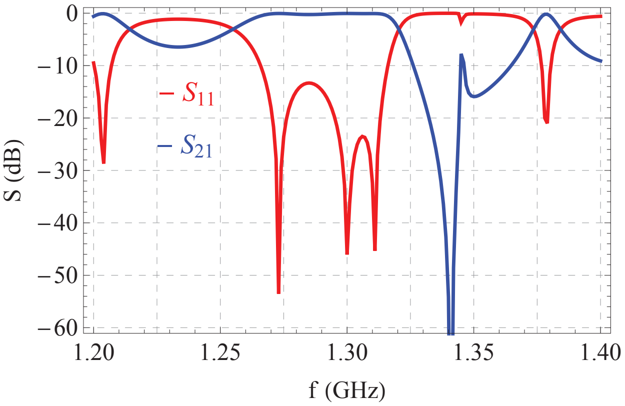

Figure 7: The S parameters of the test box for conditioning.

SUMMARY

The RF design of the FPC for BERLinPro is nearly completed. From the RF point of view, the surface fields in the coupler are within the acceptable limit, however, the 4 MHz bandwidth of the coupler is narrow. Detailed calculations on the coupler kick and its effect on beam emittance are presented in [8]. The thermal analysis and multipacting effect studies are underway. The fabrication and RF conditioning of the coupler are the next steps forward.

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