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HIGH POWER COUPLER CONDITIONING FOR bERLinPro ENERGY RECOVERY LINAC INJECTOR*

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Abstract

Helmholtz Zentrum Berlin is currently finalizing the construction of the demonstrator Energy Recovery Linac (ERL) bERLinPro [1]. The first part, which will be commissioned, will be the injector consisting of a superconducting RF (SRF) photo-injector (Gun) and a Booster module made up of three two cell SRF cavities. For the latter the 2.3 MeV beam from the gun needs to be accelerated to 6.5 MeV, whereas one Booster cavity will be operated in zero-crossing mode for bunch-shortening. Thus, for the final stage with a 100 mA beam, the twin power couplers of the Booster cavity need to deliver up to 120 kW in travelling continous wave (CW) mode at 1.3 GHz each. To achieve that, a dedicated coupler conditioning setup was installed and commissioned. Here, we will present the first conditioning results with the bERLinPro Booster fundamental power couplers in pulsed and CW regime

INTRODUCTION

For the bERLinPro ERL [1] the Booster module housing three two cell SRF cavities needs to accelerate the beam from about 2.3 MeV of the SRF photo-injector [2] to 6.5 MeV, whereas the first cavity will be used in zero-crossing mode to allow bunch shortening for the injection into the merger/recirculator section. Besides transmitting in total 420 kW power to the beam, the acceleration process in the Booster needs to preserve the low beam emittance from the photo-injector. Thus, a coupler design needs to be optimized in withstanding the high thermal load by this power level and also minimize any influence on the beam by transverse field components by the geometry variation caused by the coupler arrangement to the field symmetry.

Figure 1 depicts a schematic of the coupler design and how it is attached to the cavity. To minimize the power load per coupler and to mitigate kicks by the field distorted by the coupler as well as emittance increase, two couplers power one cavity. The coupler design is a modification of the C-ERL injector cryo-module coupler [3] and features a single window, fixed coupling and avoids such any bellows exposed to RF. Mechanical variations during e.g. cool-down are compensated by the doorknob part itself and bellows outside the module in the waveguides. Cooling is provided by 5 K and 80 K helium heat intercepts. The major heat transfer is by water cooling of the inner conductor, the outer conductor of the warm part, the doorknob section and the ceramic

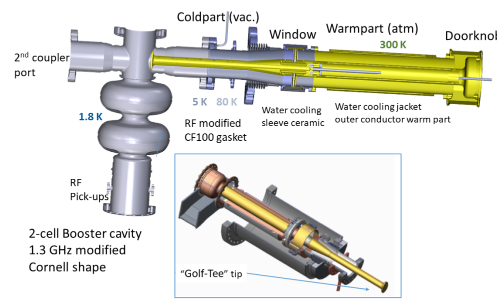

Figure 1: Schematic overview of the bERLinPro Booster injector coupler. The insert gives an better view on the Golf-Tee shaped antenna tip and the doorknob transition.

window by a copper sleeve. More information on the RF and mechanical design can be found here [4] and here [5, 6]. The antenna tip is designed such, that at full beam current, the tip needs to be flush with the beam tube to achieve the desired coupling value. For the first stage of the ERL, the SRF photo-injector will be limited by power coupler and thus deliver at target beam energy of 2.3 MeV up to 6 mA. Hence, it was decided, to assemble the Booster module with the power couplers retracted by a distance ring of 20 mm thickness to increase the loaded Q for optimum coupling for the lower average current goal, which will also significantly decrease the power consumption of the facility in the first years. Table 1 shows an overview of the operation parameters of the Booster for both stages. The power couplers can thereby be conditioned to a more relaxed target level, but still one coupler pair will be powered to the full design range of 120 kW to demonstrate the capabilities for the future upgrade.

Table 1: Parameters of the 1.3 GHz SRF Booster Cavities Operated On-crest and in Zero-crossing Mode

Parameter	**Value at 100 mA**	**Value at 6 mA**
Loaded Q	$1.05 \cdot 10^5$	$1.74 \cdot 10^6$
$f_{1/2}$	6.2 kHz	374 Hz
V_{acc}	0.56, 2.1 MV/m	0.56, 2.1 MV/m
E_0	4.833, 19 MV/m	4.833, 19 MV/m
Φ_{acc}	-90, 0 deg	-90, 0 deg
Penetration depth	2 mm	−18 mm
$P_{forward}$ TW	3.4, 220 kW	0.2, 13.8 kW
$P_{forward}$ SW	3.4, 54 kW	0.2, 3.45 kW

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In this paper, an overview of the conditioning process is given and some example data from the first coupler tests with the first two pairs being installed on the teststand.

CONDITIONING SETUP

To condition the couplers to target power level in traveling and standing wave regime a dedicated RF testbox has been designed and built. It allows room temperature tests up to 150 kW and comes with extensive diagnostics based on expectations of coupled thermal-RF simulations, but also observations done in the past at KEK. All critical points are measured temperature wise by PT-100 sensors, all water flow channels are measured including the inlet and outlet temperatures. This allows to calculate power deposited in the different cooling channels. For that reason, each channel for the conditioning is controlled by a separate set of flow meter and temperature sensor. In addition to external monitoring with an IR camera, each ceramic's temperature is measured with an Raytek IR sensor. Also, each coupler is equipped with a light fiber ARC detector and an electron pick-up similar to XFEL couplers [7]. Peak power meters are installed on directional couplers attached to the teststand to obtain forward and reflected signal at the input upstream coupler and the power level transmitted by the 2nd downstream coupler. From assembly to conditioning, the following steps are taken:

- Cleaning of all parts
- ISO 4 cleanroom assembly of coupler coldpart to testbox, pumping and leak check
- Assembly of warmpart, cooling water lines, doorknob transition in local cleanroom
- Vertical transport of setup to testing location inside enclosed carrier system
- Shift to horizontal conditioning position, 120 °C baking of the vacuum part
- Connection of cooling water and final diagnostics
- Check of S-parameters of the setup by vector network analyzer
- Connection of RF waveguides, low power tests with klystron, check power balance
- Conditioning starts at 40 Hz and 1 ‰ with 250 kW klystron from CPI limited to 150 kW output.

Figure 2 gives an impression of the different assembly steps from cleanroom to the set up at the test location in the bERLinPro accelerator hall. The conditioning procedure (see Fig. 3) follows a proposal by [8] ramping up the couplers at short pulses at 40 Hz and stepwise increase the power to an intermediate level until switching to a higher target level until the power goal is fulfilled, then an increase of the pulse length follows with a new set of power cycles. The process is interlocked by vacuum level, sudden increase of reflected power, occurrence of arcs or increase of temperatures above a predefined limit. The increase or even holding of the current power level is controlled by the vacuum signal with thresholds for increase, small increase, hold and interlock. Interlock to shut off RF was set to $5 \cdot 10^{-6}$ mbar.

COUPLER CONDITIONING RESULTS

The first coupler pair was also used to commission the teststand. After that trial, the normal CF gaskets were exchanged with RF optimized versions closing the gap and decreasing the measured S_{11} parameter from −25 dB to −35 dB. The teststand such baked once more to 120 °C and commissioning in pulsed mode went quite smooth with only few interlock events by vacuum activity up to 90 kW at 40 Hz and 10 % duty cycle (see Fig. 4).

No excessive heating was observed and thus conditioning resumed with lower target value for phase 1 operation of bERLinPro to reach 40 kW forward power in CW traveling wave and about 16 kW in standing wave. This was quickly achieved without any events and a heating of the ceramic window of 0.25 K/kW was extracted, which hints at a possible operation of the couplers at the 120 kW target power level. Figures 5 and 6 display the power ramps and window heating measured by IR sensors for the CW traveling and standing wave conditioning.

Figure 7 shows a summary of the conditioning of the 2nd pair. Here, we saw a larger imbalance in the ceramic window heating, pointing at a larger mismatch between the installed couplers. However, above some power level some arc event was triggered coming with a large vacuum event, which in addition fired the interlock. After that occurence, above a threshold of 13 kW the vacuum level increased and the downstream coupler, having a larger temperature gradient with power at the window from the beginning, showed to switch to an exponential increase of that temperature with power. This hints at some field dependent emission process hitting and thus heating the window. It needs to be checked, whether the window was harmed and eventually some remaining particulate contamination led to this behavior. This coupler will be checked within the cleanroom. Still, both couplers showed below that threshold gradients of 0.2-0.3 K/kW, where the upstream coupler kept the lower value also above that power threshold.

CONCLUSION

The power coupler teststand for the bERLinPro injector was successfully commissioned and two sets of power couplers were conditoned. Both pairs fulfill the power requirement for the 6 mA operation of the first stage. The first pair was conditioned to 40 kW CW in traveling wave and 15 kW in standing wave. Also, 90 kW at 10 % was reached in pulsed mode with that pair. The cooling showed no unexpected heating of the coupler beyond the calculated levels, far below the stress limits. The heating of the ceramics by 0.25 K/kW in CW traveling wave matches the expectation

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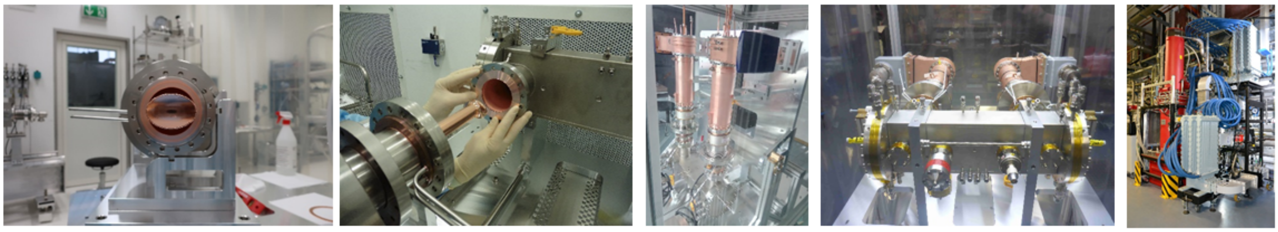

Figure 2: Overview of the steps taken from cleanroom assembly to final setup at test location of the conditioning set up.

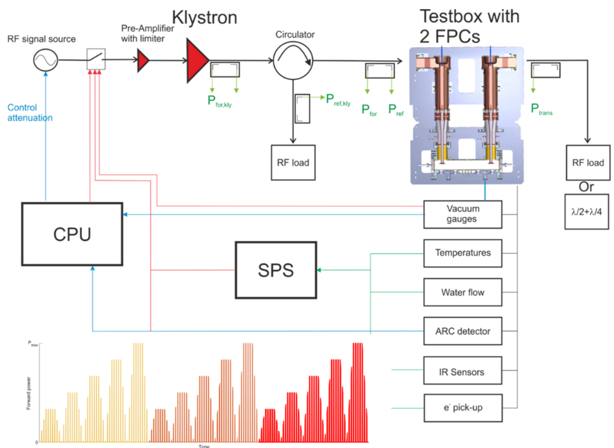

Figure 3: Scheme of the conditioning procedure: The pulse width is increased from a set of power ramps to the next denoted by color code. For each power level a ramping up and back down is performed.

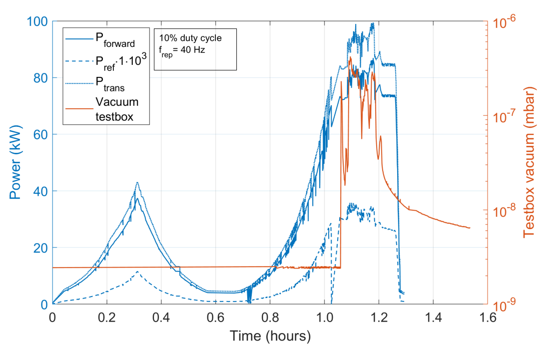

Figure 4: Intermediate result of first condition series with 1st pair reaching about 90 kW forward power at 10 % duty cycle with 40 Hz repetition rate displaying the three power signals and testbox vacuum with time.

given by the coupled simulations and should allow an operation up to 120 kW with a temperature level of 338 K of the ceramics. The second set showed some increase in vacuum activity above 13 kW along with an exponential increase of the window temperature above this power threshold. This coupler pair will be inspected in the cleanroom for damages or spots on the ceramic to decide the further treatment. Conditioning of the two following pairs should resume after this conference.

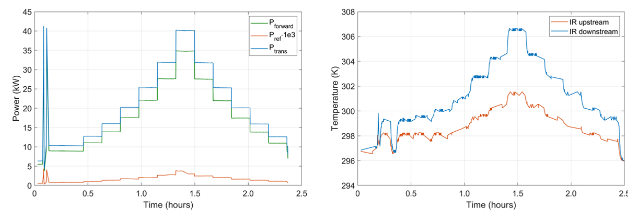

Figure 5: CW power ramps in traveling wave mode with corresponding heating at the ceramic windows measured by infrared sensors.

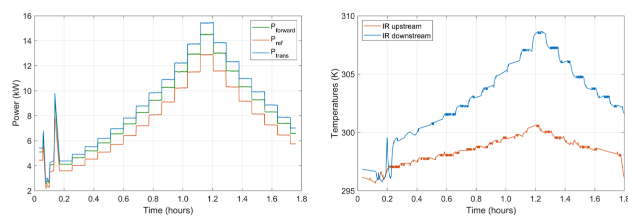

Figure 6: CW power ramps in standing wave mode with corresponding heating at the ceramic windows measured by infrared sensors.

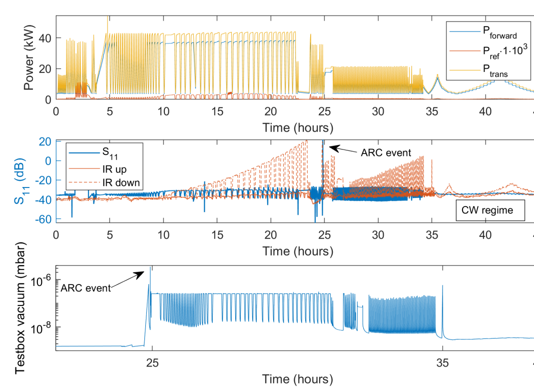

Figure 7: Part of the conditioning series of the 2nd coupler pair displaying peak power, S_{11} parameter, ceramic window temperatur and testbox vacuum with time.

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