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HIGH POWER COUPLER R&D FOR SUPERCONDUCTING CH-CAVITIES

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Abstract

The upcoming demands of the future research programs at GSI exceed the technical opportunities of the existing GSI UNIversal Linear ACcelerator (UNILAC). Besides, the existing machine will be exclusively used as an injector for FAIR (Facility for Antiproton and Ion Research) providing high power heavy ion beams at a low repetition rate for injection into a heavy ion synchrotron. A new dedicated superconducting (sc) continuous wave (cw) linac is crucial to keep the GSI research program competitive. The first part of the cw-linac, comprising a 217 MHz multi gap Crossbar-H-mode (CH) cavity surrounded by two sc solenoids inside a cryostat, already served as a prototype demonstrating reliable operability in a realistic accelerator environment. A sufficient high power RF-coupling concept is needed to feed this newly developed cw-RF cavity with up to 5 kW of RF-power in cw-mode. A high power coupler test stand was recently built to provide for a testing environment; further upgrade measures of this test area are foreseen in the next future. This contribution deals with the recent coupler R&D for the demonstrator set up. Besides that simulations of thermal losses at the coupler (inside the RF-cavity) will be shown as well.

INTRODUCTION

The 13 m superconducting continuous wave linac proposed to be built at the GSI, comprises Crossbars-H-mode (CH) RF-cavities, to accelerate heavy ions up to 7.3 MeV/u [1]. The first part of the accelerator, called 'Demonstrator', comprises one CH-cavity and two 9.3 T solenoids in a cryostat. This structure was already successfully tested with beam in summer 2017 [2–4]. It was the first sc CH-cavity in the world running with beam. In the next stage an advanced module consisting of three CH-cavities [5], a rebuncher and two solenoids will be set up for further testing. This module will be the prototype for three following similar modules (Fig. 1) to complete the entire cw-LINAC. Recent beam dynamics studies indicate, that only 2 of the modules need a rebuncher [6]. The heavy ion beam is provided by the GSI - High Charge State injector (HLI).

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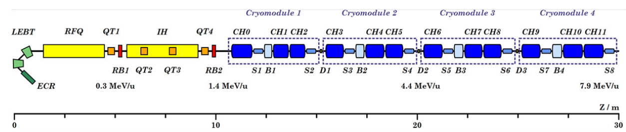

Figure 1: Recent desing of the cw-LINAC at GSI made with four standard cryo modules [7].

HIGH POWER COUPLER FOR CH-CAVITIES

For suitable coupling the RF-cavities are equipped with a capacitive, coaxial power coupler [8]. The design is a modification of an existing Fermilab power coupler [9]. Noteworthy is a diameter jump from a $3\frac{1}{8}''$ rigid line to a CF-40 line since the space at the cavities coupler port is strongly limited. The reflection caused by a parasitic capacitance due to the changing diameters is canceled out by a shift between the diameter jump the of inner and outer conductor, called "gap" (see Fig. 2). The two RF-windows of the coupler are coated with TiN for a lower secondary electron yield.

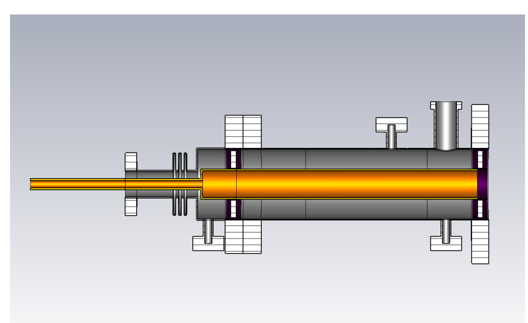

Figure 2: Cross section of the CST Microwave Studio [10] - coupler model.

COUPLER TEST STAND

A coupler test stand was established at GSI, where two couplers can be tested and conditioned in paralell. It features a quarter wave resonator (QWR)-type cavity (see Fig. 3) with an extended center-tube, presented in [11]. It has a broadband RF-transmission of ± 10 MHz. A 5 kW cw solid

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state amplifier is used to power the test stand. Each coupler is equipped with a pressure sensor and two Langmuir probes to detect multipacting. A temperature sensor is attached to each RF-window. The test configuration also includes two directional couplers, with connected power meters.

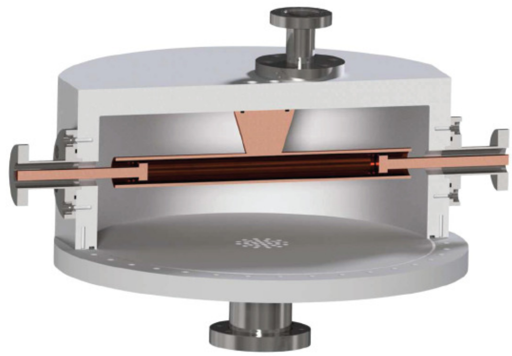

Figure 3: Cross section of the QWR-type test cavity [11].

COUPLER TESTS

Two couplers have been tested and conditioned in April 2017. Initially the conditioning was performed in pulsed power mode with a duty factor of 1%. During the conditioning campaign the duty cycle was continuously increased up to cw-mode. The power was boosted up to 5 kW in pulsed mode and 2.5 kW in cw-mode.

Figure 4 shows the pressure changes in the couplers during an early conditioning campaign. During that degassing could be observed, that subsides over time.

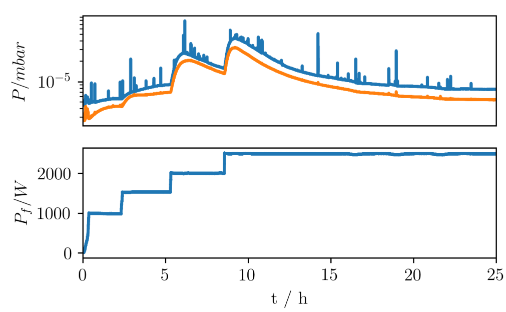

Figure 4: Degassing events in the input coupler (blue curve) and the output coupler (orange curve) during conditioning.

In a final step the forwarded power was changed randomly as shown in Fig. 5. After changes in power affected the multipacting current and the pressure only marginally, the coupler was considered as conditioned.

During cw-power conditioning the couplers showed major heating at the RF-windows. In Fig 6 the temperature measured at the windows are depicted. The input coupler's cold window reached 91.1 °C. This is of course to high for a usage in a cryogenic environment. The forward power was not increased further, because thermal stress could potentially destroy the windows.

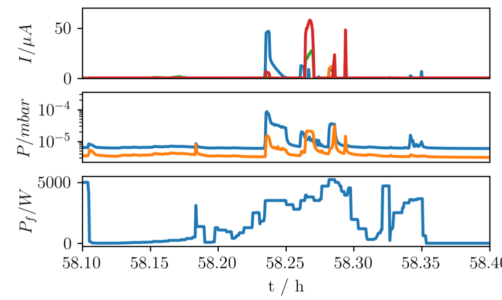

Figure 5: Changing the power randomly in the final conditioning phase.

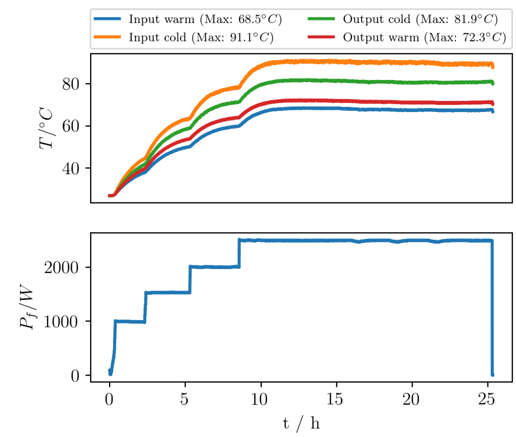

Figure 6: Temperatures of the coupler windows during conditioning with cw-power. Orange (cold window) and blue (warm window) represent the the temperatures of the input coupler. Green (cold window) and red (warm window) represent the the temperatures of the output coupler.

Despite the heating, one coupler was used successfully in the beamtest two months later.

THERMAL SIMULATION

To estimate the heat flow from the coupler to the cryostat, simulations with CST Microwave Studios were performed.

An RF and a thermal simulation were coupled, reconstructing the temperature profile of the coupler test. With this the heat losses of the coupler could be calculated.

For this a detailed model of the coupler was developed. This included the heat transfer to the environment. To size the heat transfer an experiment was done. A coupler was equipped with nine temperature sensors and heated in an oven. After taking the coupler out of the oven, the cooling process was recorded. Besides that the cooling process was simulated. The heat transfer coefficients and other parameters of the simulation were adjusted, that the curves of the experiment and the simulation were overlapping (shown in Fig. 7).

After setting the right parameters the main simulations could be started. In the first step an RF- simulation was

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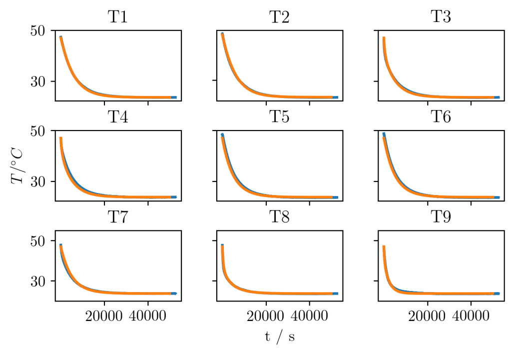

Figure 7: Cooling process of the coupler after heating in an oven for simulation (orange) and experiment (blue) with nine different temperature sensors attached to coupler (T_1 - T_9).

performed, to evaluate dielectric losses and losses caused by surface currents. These losses were imported to a thermal simulation acting as a heat source. The outer flanges was set to room temperature. With their relatively high mass the adjoining cavity and RF-line could be considered as heat a sink.

Due to the TiN coating of the coupler windows, the loss factor $tan(\delta)$ was significantly higher than for standard Al_2O_3 ($tan(\delta) \approx 10^{-4}$).

As the losses caused by surface currents were fixed, the loss factor was increased, trying to reconstruct the temperature profile of the coupler test. Figure 8 shows the temperature determined by the simulation with changing $tan(\delta)$. The yellow diamonds mark the loss factor $tan(\delta) = 0.0492$ to reconstruct the temperatures rise during the coupler test.

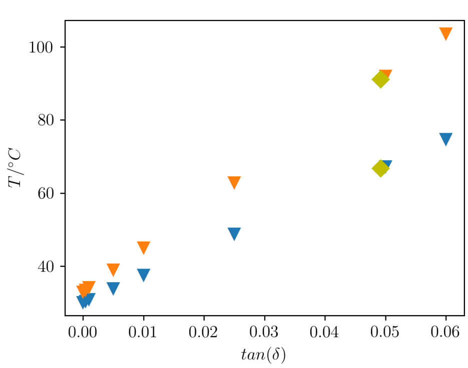

Figure 8: Temperature of the coupler windows with increasing loss factor. The yellow diamonds mark the $tan(\delta)$ reconstructing the temperatures during the coupler test.

Under these conditions a total heat loss of 70 W was calculated, when using a forward power of 2500 W (for more details see Table 1).

The static heat load was calculated to 2.73 W. The total calculated heat load is 72.81 W. It is obvious that the heat loss is caused mainly by the coating of the windows. The windows have a TiN coating of 25 nm. This increases the loss factor significantly [12]. A new advanced coupler is going to be designed without any window coating. Changes to the window distance and the *gap* will be made for improved RF-performance. The improved design could be the first of series for the cw-linac.

Table 1: Heat Losses Calculated by CST Microwave Studio for Three Different Forward Power Levels

P_f	1 W	2500 W	5000 W
Warm window	0.013 W	31.75 W	63.50 W
Cold window	0.014 W	34.08 W	68.16 W
Surface current	1.7×10^{-3} W	4.25 W	8.5 W
Total	0.028 W	70.08 W	140.16 W

FUTURE COUPLER-TEST-STAND

Several other couplers have to be tested and conditioned during the cw-linac commissioning. Therefore the test stand has to be extended and further improved. The design of a movable reflector already successfully used at Fermilab, [13] was adapted to the coupler's frequency of 217 MHz recently and is manufactured right now (shown in Fig. 9).Located in front of the input coupler along the RF-line, it allows to operate the test stand in a resonance mode for increased power.

A movable ring on the inner conductor is applied as a semitransparent mirror analog to an optical resonator. It can be moved more than half the wavelength. At the other side of the coupler test stand are shorted wave guides of variable length, acting like a full mirror.

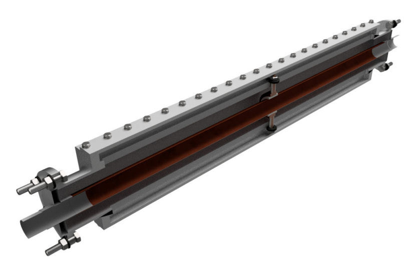

Figure 9: Model of the movable reflector.

To ease the process it is intended to automate the conditioning process in the future.

SUMMARY AND OUTLOOK

Two 217 MHz coaxial power coupler were tested and conditioned at GSI. Simulations were performed to estimate the heat losses of the coupler. The results of the testing and the simulations will be used to further improve the design. An improved coupler could be the first of a series for future cw-linac cavities. A movable reflector is manufactured at the moment to extend the existing coupler test stand at GSI.

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