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TEST AND COMMISSIONING OF THE HELIAC POWER COUPLER

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Abstract

The superconducting continuous wave (cw) heavy ion HElmholtz LInear ACcelerator (HELIAC) is intended to be built at GSI in Darmstadt. With its high average beam current and repetition rate the HELIAC is designed to fulfill the requirements of the super heavy element (SHE) research user program and the material sciences community at GSI. The accelerating cavities are of the superconducting Crossbar H-mode (CH) type, developed by GUF. Within the Advanced Demonstrator project, the first cryomodule, consisting of four cavities is scheduled for commissioning with beam in 2023. The former RF power couplers introduced a high heat input into the cryostat. Therefore, the coupler is redesigned at HIM in order to not only reduce the heat input but to provide an overall improved power coupler for the HELIAC. It is designed for a maximum power of 5 kW cw at the frequency of 216.816 MHz. A prototype has been tested and commissioned recently. This includes several RF-tests at room temperature and in cryogenic environments. The results of these tests will be presented in this paper.

INTRODUCTION

The superconducting HELIAC (Fig. 1) is foreseen to serve as the main accelerator for SHE research [1] and material sciences at GSI while the UNIversal LinAC (UNILAC) is upgraded as injector for the Facility for Antiproton and Ion Research (FAIR) [2]. HELIAC consists of a normal conducting injector [3, 4] and a superconducting linac [5] comprising twelve CH-cavities [6, 7]. After completion of the Demonstrator project, and first successful operation of a CH cavity [8] with heavy ion beam [9], the linac is currently in an advanced R&D-phase, called the Advanced Demonstrator project [10]. For this purpose, the first complete cryomodule consisting of three CH cavities, a CH-buncher [11, 12] and two superconducting solenoids is going to be prepared for a beam test.

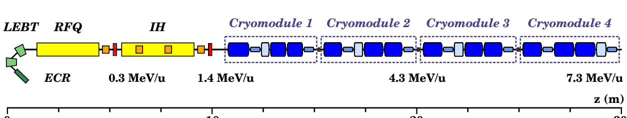

Figure 1: Layout of the HELIAC with its normal conducting 1.4 MeV/u injector and the superconducting part, comprising four cryomodules with three CH-cavities (beam energies up to 7.3 MeV/u).

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HELIAC POWER COUPLER

In order to overcome serious operational problems, the original design approach of the power-couplers [13] has been further improved and thus a new advanced design could be developed [14]. The revised coupler can be disassembled modularly into individual components, to allow easy cleaning and assembly; potentially the replacement of individual components is possible in case of malfunction. As the previous coupler, the current design (see Fig. 2) is based on a coaxial, capacitive 3 1/8"-RF-line (2, 4) and comprises two ceramic windows (1). The diameter of the line is tapered (3)

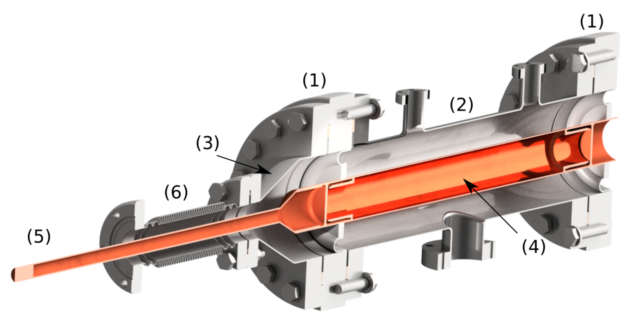

Figure 2: Cross section of the recent power coupler design for the HELIAC.

to fit the cut-off tube of the resonators in the cold section. In order to allow variable coupling, the coupler is equipped with a bellow (6) which has a total stroke of 30 mm. With 28 corrugations and a wall thickness of only 0.15 mm the bellow also ensures a minimal static heat load into the cavity.

Figure 3 depicts the RF window flange (1), where an U-shaped spring connects a CF100-flange with an Al_2O_3-disk-window. This spring is made of Invar42, a nickel-iron alloy

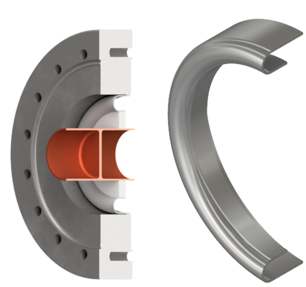

Figure 3: Cross-section of coupler window flange (left) and U-shaped spring (right).

with the same coefficient of thermal expansion as Al_2O_3 and thus minimizes the probability of damage caused by thermal

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stress during manufacturing and use. Due to this design, the ceramic has a comparatively small volume, resulting in low dielectric losses. The space between the windows, is separately evacuated via a CF40 connection. Two CF-16 outlets allow the connection of diagnostic instruments.

Table 1: Coupler Design Parameters

Parameter	Value
Type	coaxial, capacitive
Number of RF-windows	2
Operating frequency	216.816 MHz
S_{11} at 216.816 MHz	–60 dB
Coupling factor (β_e)	10 – 1000
Max. forward power	5 kW
Duty factor	100%
Static heat load to 50 K	3.5 W
Static heat load to 4 K	0.82 W
Dynamic heat load to 4 K	0.5 W
Total RF losses	< 6 W

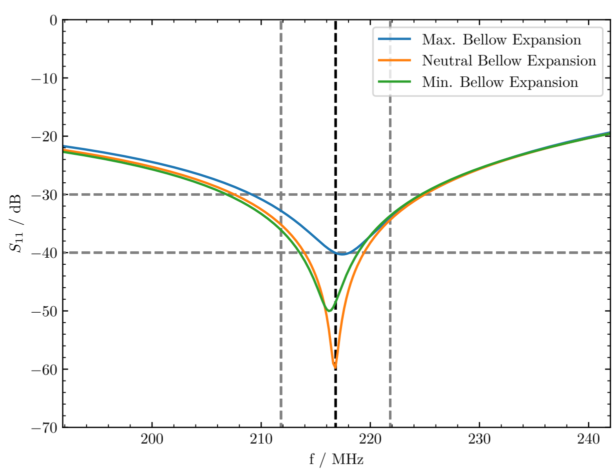

Figure 4: Reflection coefficient S_{11} (as a function of the RF-frequency f) of the coupler for different bellow expansions.

The coupler was designed in such a way, that a reflection of −60 dB to −40 dB can be expected at a frequency of 216.816 MHz – depending on the bellow expansion. In a frequency range of ± 5 MHz, a reflection coefficient of −30 dB is not exceeded (see Fig. 4). All components are designed for operation of up to 5 kW continuous wave power in transmission and full reflection at arbitrary phase, whereas the maximum power in operation is only 3 kW. The cold window acts as a thermic intercept as it is anchored to the 50-K-shield of the cryostat. In order to provide for a low static heat input, the coupler components were constructed of stainless steel (316L) with a wall thickness of 0.75 mm. To reduce ohmic losses the bellow and inner conductor (4) are copper coated. Table 1 reveals an overview of the major coupler characteristics, whereby the values of the dynamic heat load and the total RF losses are referred to a beam current of 0.1 emA at a mass to charge ratio of 6.

COUPLER TESTS

In early 2020 a first prototype of the coupler was produced. Several different tests have been conducted at room temperature and in a cryogenic environment, in order to test RF and thermic properties. Most of the test activities were performed on a coupler test bench under high-performance conditions at room temperature. The prototype of the antenna was provided at the end with a thread so as to allow it to be connected to another inner conductor; thus, it can be used with a simple vacuum cross chamber instead of an RF test cavity, making the test stand (see Fig. 5) compact (1.5 m long) and simple. For tests in transmission the opposite side of the vacuum cross-chamber can be equipped with another antenna and window, that adapts back to a regular RF-line. For tests in reflection, the cross-chamber remains closed on one side. Peak power of up to 5 kW in transmission or full reflection were applied over several months. It was demonstrated that the current design fully meets the requirements of long term high-power coupler-operation.

For conditioning of the coupler a relatively long time had to be spend. Getting the coupler into an fully operational state took several days to weeks, where the process had to be constantly supervised. To reduce the personnel effort, software was developed to automate the coupler conditioning process. The diagnostic data of the coupler is read out permanently, and an appropriate power level is set based on predetermined criteria. The power is increased gradually until the target level is reached. The status of the test stand can be read out and the operating parameters can be set remotely at any time.

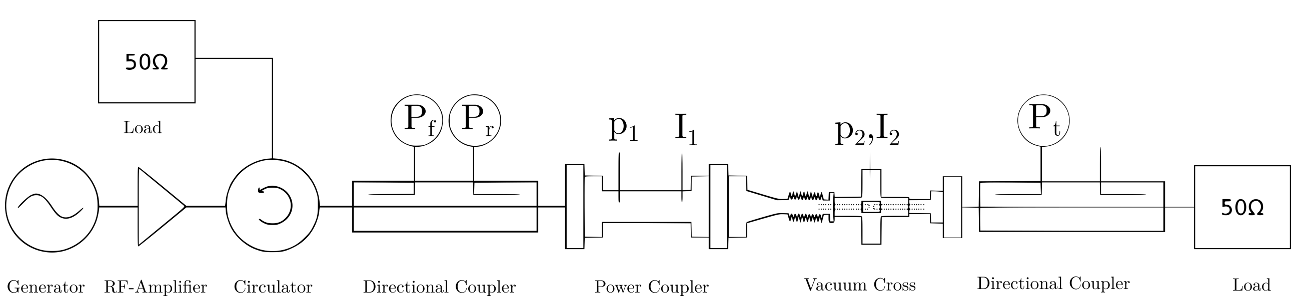

Figure 5: Sketch of the coupler test stand for high power operation.

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An RF-window as a key component was cooled down to 4 K in a bath cryostat. In this test the sensitive component remained vacuum-tight regardless of several cold-warm cycles. In order to obtain the static heat load and the temperature distribution along the coupler, a prototype was installed on a dummy-cavity inside the first cryomodule. The coupler-prototype was equipped with ten temperature sensors. The observed heat input of the coupler to 4 K was below the measurement range of the gauge and is thus well below 1 W.

Apart from minor multipacting issues emerged with at a few number of prototypes (see next section), the tests showed that the coupler design fully meets the requirements and is therefore ready for testing with beam.

MULTIPACTING SUPRESSION

In addition to conditionable multipacting thresholds, multipacting incidents also occurred at quasiperiodic intervals in some prototypes. These events were limited to the area between the windows and proved not to be conditionable. This type of multipacting events were observed at power levels between 1000 W and 3000 W and occurred when remaining at one power level for a longer period of time. In some cases, the interlock level of the pressure sensor was exceeded, resulting in repeated shutdowns. For this reason, a Bias-T-configuration (see Fig. 6) is applied for multipacting suppression with the HELIAC couplers. Thereby a DC voltage between −600 V and 600 V can be applied to the inner conductor, which eliminates the conditions for multipacting. The DC voltage is supplied via a stub, which is blocked for the RF field due to a choke coil . On the other hand the DC voltage is shielded from the RF-generator by a capton foil on the inner conductor, which acts as a capacitor.

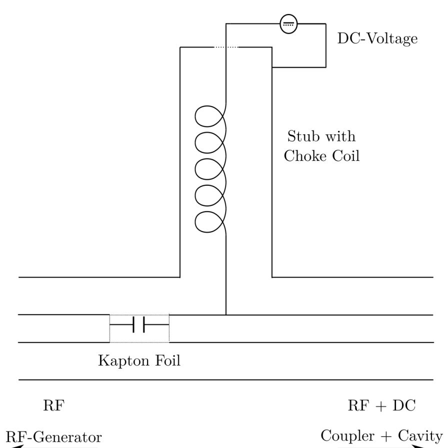

Figure 6: Diagram of the Bias-T.

To test the aforementioned multipacting suppression a deliberately soiled coupler with a vacuum of ~1×10^5 mbar was mounted at the test stand. As shown in Fig. 7, the vacuum pressure increases massively due to strong multipacting activities as soon as the forward power is abruptly switched on without bias voltage. Hence the interlock immediately interrupts operation. By switching on a bias voltage

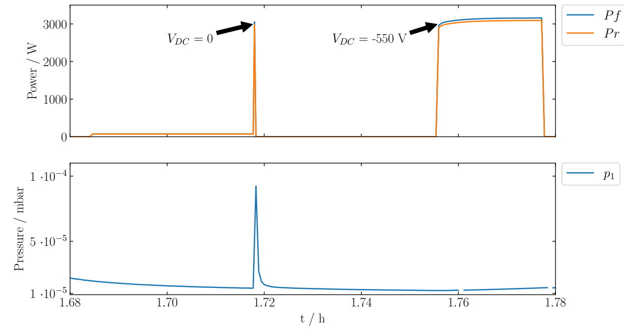

Figure 7: Test of the Bias-T with coupler, applying a bias voltage, RF-power can be switched on at maximum level without prior conditioning of the coupler.

of −550 V, all activities are suppressed, allowing operation without prior conditioning. It was found, that even with a completely unconditioned coupler, operation at full power is possible without any occurrence of multipacting if a sufficient bias voltage is applied. This ensures safe operation of the coupler and a significantly reduced time span is required for commissioning the cryomodules.

CONCLUSION AND OUTLOOK

The current design of the HELIAC power coupler underwent extensive testing campaigns. High-power tests verified the suitability of the design for long-term operation at high power, whereas tests on the cryomodule showed a static heat input as low as expected. The first cryomodule (CM1) of the HELIAC will be equipped with four couplers and is expected to be commissioned with beam in Q3 2023. Serial production of the coupler components is planed to start after successful coupler performance, confirmed during beam commissioning of CM1.

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