FIRST HIGH POWER TESTS AT THE 325 MHz RF TEST STAND AT GSI

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Abstract

A dedicated RF test stand for testing RF components and accelerating structures at 325 MHz has been put into operation at GSI. It allows testing the klystrons and circulators as well as the RFQ and the CH-acceleration cavities for the planned FAIR Proton Linac (p-Linac) and further cavity projects. The system integration has been completed and first high power tests with the CH prototype cavity were successfully performed. The operation parameters are 2 Hz repetition rate and 200 microseconds pulse length. Investigations on the critical path from wave guide to coaxial high power cavity coupler have been made. Performance measurements of the klystron, circulator and directional couplers with up to 2.7 MW on dummy load and the following conditioning process of the CH-prototype cavity with its coupled RF structures will be presented. Additionally the results of the conditioning of a ladder RFQ prototype are shown.

INTRODUCTION

The 325 MHz test stand at GSI was successfully operated in 2015 [1]. A Thales TH 2181 klystron is able to deliver up to 3 MW RF peak power. A linac 4 klystron modulator was rented from CERN and integrated into the GSI test stand and its interlock systems. All peripheral components, such as circulator, RF load and wave guides have been tested up to the nominal power [2].

Wave Guide Directional Coupler Calibration

Two pairs of directional couplers for measuring the forward and reflected RF power have been installed at the klystron output. Three pairs of directional couplers inserted into the wave guides between circulator and acceleration cavity are used for RF measurements, interlocking and cavity tuning. To achieve an accurate RF power measurement all wave guide WR2300 directional couplers have been calibrated with a special procedure [3]. An external compensation circuit has been installed to improve the directivity of the couplers up to -50 dB even with coaxial-N-transitions and waveguide loads providing a limited matching of worse than S_{11} = -30 dB. Precise power measurements and a reliable klystron protection at VSWR<1.2 in case of failure of the circulator are now assured. A transition from wave guide to coax 6-1/8 inch allows the connection to the coaxial RF cavity coupler. An additional directional coupler in this coaxial section allows a comparison with the wave guide couplers.

P-LINAC CH CAVITY – LOW-LEVEL MEASUREMENS

The FAIR Proton Linac CH prototype cavity [4], developed by the IAP University of Frankfurt [5], was installed at the test stand in the concrete shielded bunker and connected to the water cooling distribution (Fig. 1). The cavity consists of two CH cavities (CH1/CH2) with a RF coupling cell in-between. Fourteen fixed and three movable tuners are foreseen. The movable tuners are located at each cavity part and at the coupling cell. The RF power is fed into the coupling cell by an inductive loop [6]. Field flatness measurements have been done for the installation of the tuners by bead pull measurements.

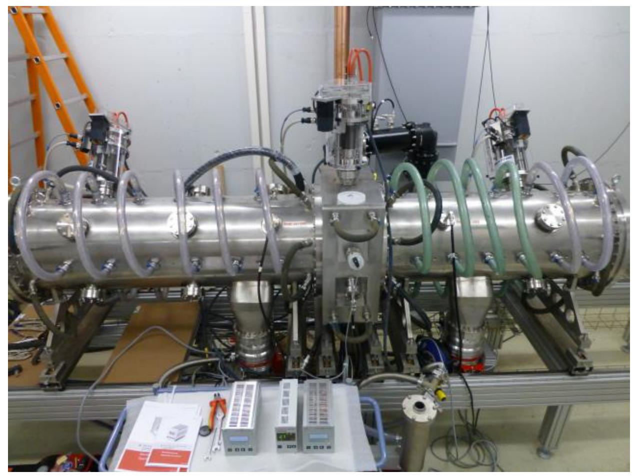

Figure 1: CH Cavity with three movable tuners and coaxial input line (black coloured).

Additional low-level measurements with a 4-port network analyser have been performed to investigate the tuner characteristics. The signal was applied to the RF input coupling loop. The RF pick-up probes at the coupling cell (S_{21}), CH1 (S_{31}) and CH2 (S_{41}) are shown in Fig. 2.

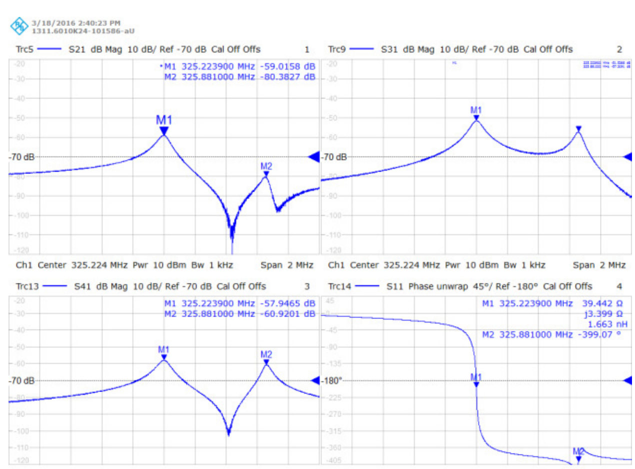

Figure 2: Low-level measurements, coupling cell (S_{21}, up left), CH1 (S_{31}, up right), CH2 (S_{41}, low left) and phase at the coupling cell input.

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The frequency behaviour depending on the position of the movable plungers has been studied. The acceleration mode is at 325.224 MHz and a second mode is nearby at 325.881 MHz but is supressed by -21 dB at the coupling cell. By moving the tuner of the coupling cell to its end positions a maximum frequency shift of 80 kHz (1.04 kHz/mm mechanical tuning range) can be achieved while keeping the CH1 and CH2 tuner at fixed position. Due to the well dimensioned water cooling of the cavity and low average RF power (<0.1% duty) only a slight frequency shift is expected during operation. Field flatness measurements should be re-performed to assure the field flatness when only the main tuner in the coupling cell is moved.

P-LINAC CH CAVITY – CONDITIONING AND HIGH POWER TESTS

The cavity design field should be reached with 1.35 MW RF pulse power (cavity heat loss). For the FAIR p-Linac a high beam load during the 35 microseconds beam pulse will require additional 883 kW which leads to a klystron power of ~2.2 MW [5]. All power lines and the coupling cell input coupler have to sustain this peak power with some additional margin. After the connection of the power lines the conditioning process was started with low power with nominal 200 microseconds pulse length at 2 Hz repetition rate. At the beginning the cavity showed an asymmetric reflected RF power depending on the movable tuner positon (Fig. 3).

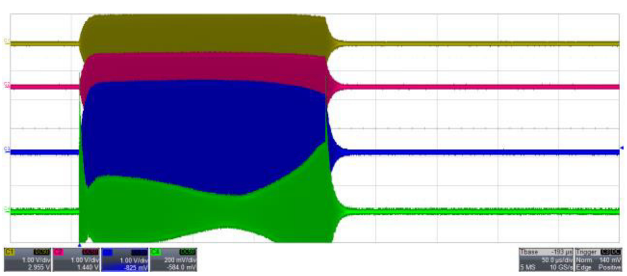

Figure 3: Conditioning process at 160 kW peak power, Cavity probe signals of CH1 (yellow), CH2 (red) and the coupling cell (blue) with different coupling factors. Green: reflected power.

The position of the minimum in the reflected power could be moved within the RF pulse by moving the tuners in the coupled cavities showing that the cavities do not behave symmetric. This effect vanished during the conditioning process and the RF power could be increased up to 2.7 MW (Fig. 4). This leads to a cavity field strength 40 percent higher than the design field without beam but confirms the design cavity input coupler.

The most critical path in the power line is the transition from WR2300 to the 6-1/8" inch coaxial part which includes four coaxial 90° elbows, a coaxial directional coupler and the cavity coupler. The coaxial line is specified up to 3 MW peak power. In case of an arc in the cavity the expected reflected and stored power increases the voltage on the RF power lines which leads to an arc in the coax, depending on position and intensity of arcing in the cavity. This arcing was clearly detected with the optical view port of the arc detection system in the power line and leads to a fast RF interlock and needs a manual restart of the RF. Figure 5 shows the forward power of the coaxial directional coupler during a typical arc where the break down at the end of the pulse is obvious. The reflected power is ~5.5 MW and depends on the position of the arc in the cavity and the line transformation to the position of the directional coupler.

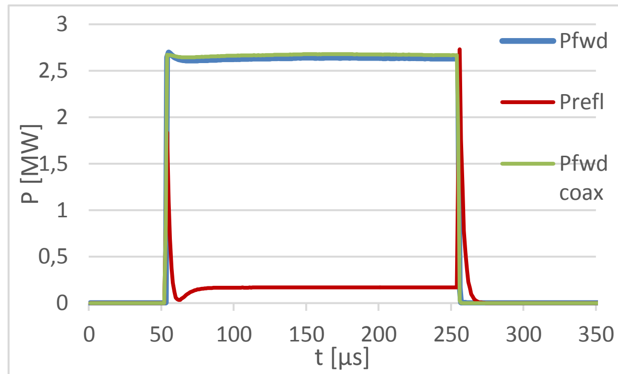

Figure 4: RF pulse after conditioning: forward and reflected power at the waveguide directional couplers (blue/red), forward signal at the coaxial directional coupler (green).

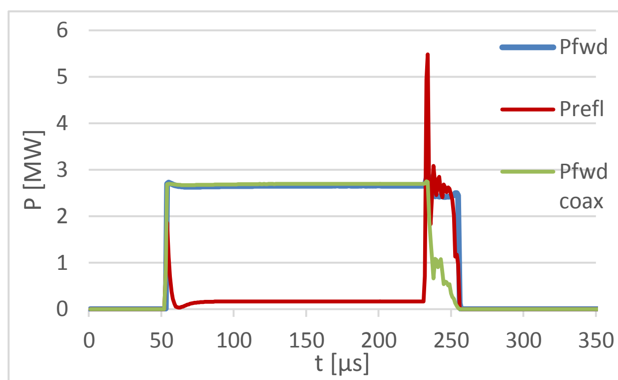

Figure 5: Cavity arcing short before the end of the RF pulse, the coaxial coupler is located near the cavity input coupler (green), forward and reflected signal in the wave guides (blue/red) between circulator and cavity.

Disassembling the coaxial line showed small damages (dots) in the inner surface of the 90° elbows. For the future p-Linac the size of the coaxial transition to the cavity might be increased to 9-3/16 inch.

The cavity vacuum during conditioning was monitored and the RF was supressed by a fast interlock if the pressure increased above $5{\cdot}10^{-7}$ mbar. The conditioning RF pulses restart automatically when the pressure is below this threshold.

P-LINAC RFQ – HIGH POWER TESTS

A proposal for a possible FAIR p-Linac ladder RFQ was initiated by IAP University of Frankfurt [7]. A 0.8m prototype RFQ section was build and delivered to GSI for first high power tests. The RFQ was placed in the test bunker beside the CH cavity (Fig. 6) and the coaxial power line length was matched for the connection.

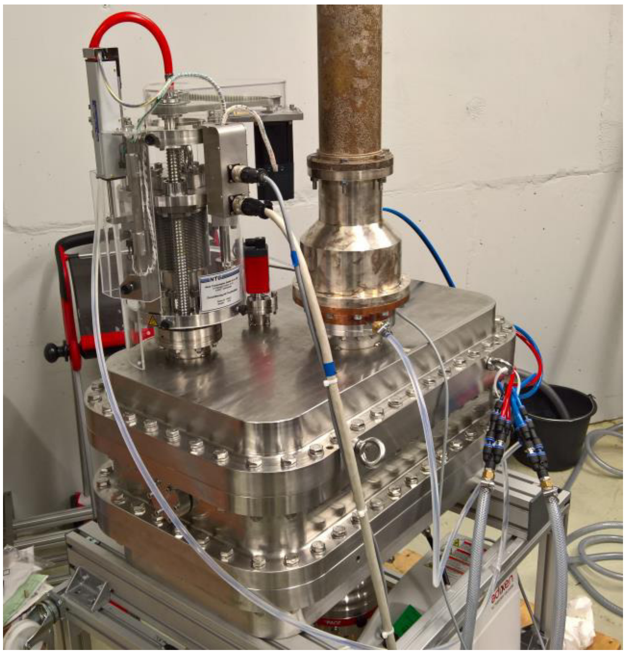

Figure 6: Ladder RFQ with movable tuner and input coupler on top of the cavity.

Power losses for the design field strength are calculated with 94 kW. Careful conditioning lead to a maximum power of 485 kW (Fig. 7) but showed some arcing in operation over several hours which did not vanish. After initial conditioning a stable operation in the order of 260 kW without arcing was possible.

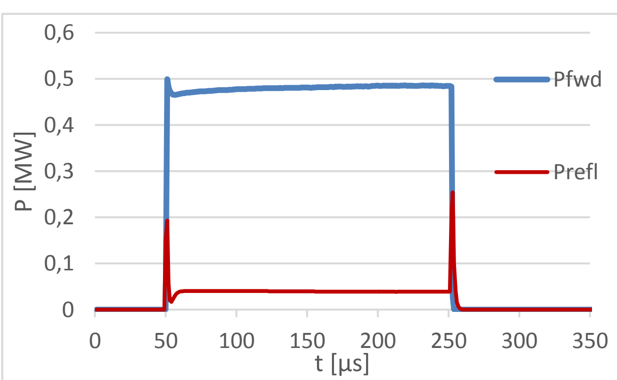

Figure 7: 0.8 m Ladder RFQ Prototype (IAP), maximum power reached after conditioning.

CONCLUSION

Calibration and first high power RF tests have been done with all components of the 325 MHz test stand at GSI followed by RF tests of the p-Linac CH prototype cavity as well as a 0.8 m ladder RFQ prototype. In both cases the cavity conditioning process was done in short time using a few hours shifts during daytime and was completed within a few days. A stable operation of the FAIR p-Linac CH cavity up to 2.6 MW is possible but is limited by the coaxial part of the RF power lines. An arc in the cavity with its reflected power leads to arcing in the coaxial elbows. An increased coaxial power line diameter is recommended for the final FAIR p-Linac layout. The coupled CH cavity behaviour concerning cooling and tuning was studied at high power for the first time. The design of the coupling loop was proofed.

The p-Linac CH cavity and the prototype ladder RFQ from Frankfurt University were easily conditioned to higher power than required.

With a new modulator the GSI 325 MHz test stand will serve as test area for all p-Linac RF components in future and for further cavity projects. This includes prototype testing for all components under development (e.g. digital LLRF controllers, PLC, interlock systems) as well as series component tests.

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