ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA022

PROGRESS OF THE KLYSTRON AND CAVITY TEST STAND FOR THE FAIR PROTON LINAC

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Abstract

In collaboration between the FAIR project, GSI, and CNRS, the IPNO lab provided the high power RF components for a cavity and klystron test stand [1]. For initial operation of the 3 MW Thales TH2181 klystron at 325.224 MHz we received a high voltage modulator from CERN Linac 4 as a loan. Here we report, how we integrated the combination of klystron, high voltage modulator, and auxiliaries to accumulate operating experience. Klystron RF operation started on a water cooled load, soon the circulator will be included and then the prototype CH cavity in the radiation shielded area will be powered. The 45 kW amplifiers for the 3 buncher structures of the FAIR proton Linac were checked at the test stand, and the results are presented here.

TRANSISTOR AMPLIFIER TEST

In autumn 2014 three 45 kW transistor amplifiers for the 3 (re-)bunchers of the Proton Linac were delivered. The alignment of the amplifiers and the RF output was improved for easier installation by replacing the standard rollers with a version that is additionally equipped with adjustable feet as shown in the bottom of Fig 1.

Figure 1: One of the 45 kW amplifiers.

We confirmed the function of the inrush-current limiter and were able to replace the 125 A mains fuses with 63 A types. This allowed us to use a 3 phase standard CEE plug, which simplifies changing of the test setup. The firmware was adjusted to the expected pulsed modes. In operation, we need a repetition rate of 4 Hz; with some margin the amplifier should work at 5 Hz and actually the amplifier can handle repetition rates of 10 Hz and higher. The required pulse length is 0.2 ms. For testing, we used 0.4 ms long pulses. Such pulse pattern is shown in Fig. 2. The amplifier bias (yellow trace) is activated 1 ms before the RF is applied. The falling edge of the green trace triggers the power measurement. The light blue trace shows the RF output.

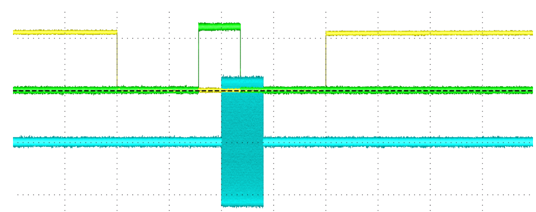

Figure 2: Amplifier test pulse pattern (0.5 ms/div).

Initial tests were conducted with a 50 Ω air cooled load at the amplifier output. The required 45 kW pulsed power was confirmed. The delay from RF-OFF command to RF-OFF was measured as less than 400 ns. From University of Frankfurt we received a compact 325 MHz test cavity structure to conduct site acceptance tests of these amplifiers under pulsed conditions driving a resonant load. This cavity was temporarily installed in a shielded area as shown in Fig. 3.

Figure 3: 325 MHz test cavity structure on support.

When discharges appear in the cavity, some power is reflected back to the amplifier. Thus we have to test the amplifier behavior not only for normal operation as shown in Fig. 4, but also for cavity conditioning.

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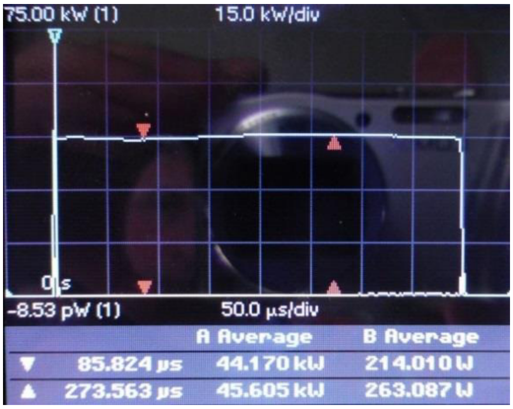

Figure 4: Undisturbed 0.4 ms long 45 kW RF pulse.

From factory acceptance test (FAT), we knew the effect of the transmission line length between amplifier output and reactive load. With initial transmission line length, the reflected power from cavity discharge resulted in a forward power higher than 45 kW and the amplifier protection system responded with a controlled shut down. This is shown in Fig. 5. The forward power (light blue) before discharge is 41.1 kW. During the discharge the reflected power (light yellow) partially adds to the forward power. The pulse stops at 54.4 kW forward power when the reflected power reaches 46.5 kW.

Figure 5: A discharge leads to amplifier shutdown.

Figure 6: No amplifier shutdown with 21 cm extension.

When we added an extension with approximate quarter wave length, reflections due to cavity discharge result in reduction of forward power as shown in Fig. 6, and the amplifier continues operation. With the extension, all 3 amplifiers delivered the full 45 kW of specified power.

KLYSTRON TEST PREPARATION

The company that originally wanted to provide the high voltage modulator for the klystron faced technical problems and could not finish their task. Fortunately the operating voltage and current of the klystrons for the CERN Linac 4 [2] are similar to the TH 2181 klystrons foreseen for the FAIR Proton Linac. The Linac 4 repetition rate of 2 Hz is lower than the 5 Hz rate foreseen for the Proton Linac. The pulse length for the proton Linac is shorter, which provides margin for operating the borrowed Linac 4 high voltage modulator. Effort was put into modifying and upgrading the existing infrastructure. The installed modulator is shown in Fig. 7.

Figure 7: Klystron modulator installed in place.

The 3 phase electric supply now provides sufficient margin for operating the high voltage modulator and pulsed transistor amplifiers at same time. At the former set-up the auxiliaries were embedded into the modulator. Thus, we provided an additional rack containing the klystron filament power supply, the 3 solenoid power supplies and the two ion pump power supplies. The company AFT managed to adapt the cooling temperature range from 30+/-1°C to available 25°C of the 3 MW circulator for the klystron. This allowed simplifying the cooling water distribution, which can handle testing of klystron and transistor amplifiers, too. The klystron heater oil tank was prepared for the CERN modulator, and the filament power supply was tested to establish the power up and shutdown procedures.

In operation of the solenoid power supplies in constant current mode, we confirmed that they work as expected. The solenoids reach thermal steady state in approximately two hours. The ion pump power supplies and the arc detection require fast acting interlocks. Accordingly the measurement & interlock rack was modified to process

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the additional signals. Careful checking of the interlock functionality and the signals processed by a PLC ensures protection of the klystron according to the manufacturer specifications. The fastest response is handled by blanking the low level RF signal within microseconds. In this context, we confirmed that the BLA 300 driver amplifier for the klystron can blank the RF signal in less than 1 µs with approximately 70 dB signal reduction. First we operated the klystron without applying RF to understand the interaction with the modulator.

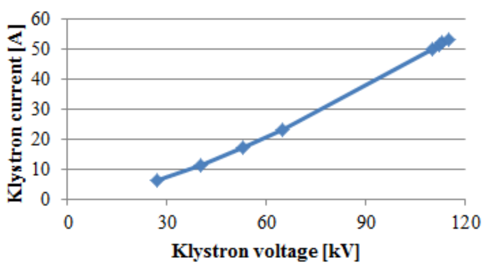

Figure 8: Klystron current vs. klystron voltage.

The klystron current as function of klystron voltage in Fig. 8 gives an average perveance of 1.39 $\mu A/V^{1.5}$. The klystron current measured with a sensor in the klystron oil tank as function of time for voltages up to the nominal value (115 kV, 53 A) is shown in Fig. 9.

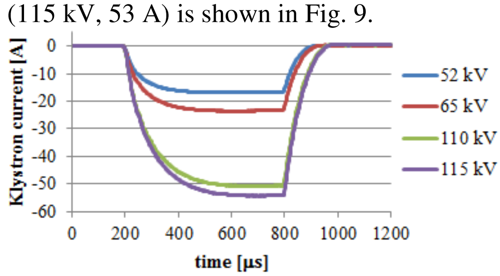

Figure 9: Klystron current measured in the oil tank.

At the end of April 2015, the condition of the test setup allowed to try RF tests with the TH 2181 klystron. Fig. 10 shows the klystron gain and output level, measured with a calibrated 60 dB waveguide coupler as function of the 300 W driver amplifier level. The driver amplifier gain is 55 +/- 0.15 dB.

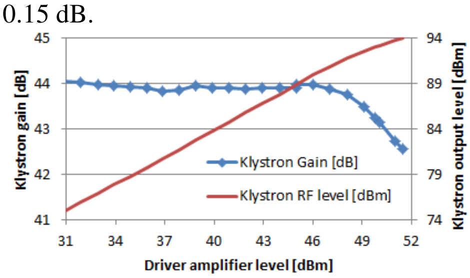

Figure 10: Driver level and klystron output power level.

With moderate 40 W drive power, the klystron output power reaches 1 MW (90 dBm). Up to this level the klystron gain is 43.9 +/- 0.2 dB. The nominal power of 2.5 MW (94 dBm) requires 140 W drive power. As shown in Fig. 11 (left), the 1 MW RF power pulse is nearly flat for the whole 200 µs long pulse.

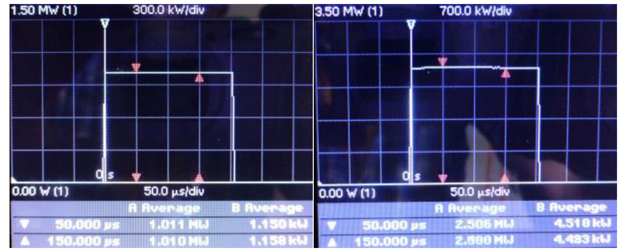

Figure 11: 1.0 and 2.5 MW klystron power (50 µs/div).

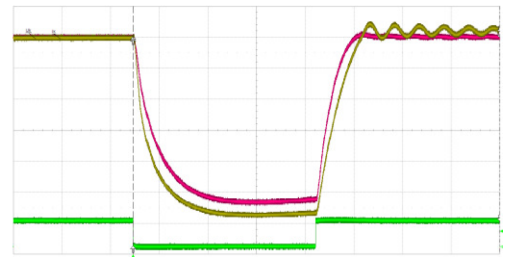

Figure 12: Modulator voltage and current (200 µs/div).

Figure 12 shows the HV switch command (green trace) together with the cathode voltage (olive trace, 20 kV/div) and the cathode current (red trace, 10 A/div). The vertical zoom in Fig. 13 shows the current (red trace, 2 A/div) and a nearly flat 200 µs long region of the cathode voltage (olive trace, 10 kV/div), indicated with an arrow, where the voltage variation is approximately 1 %. Here the bouncer circuit was not necessary and was shortened. Thus, a modified CERN Linac 4 modulator can be the basis for a cost optimized design for the FAIR pLinac.

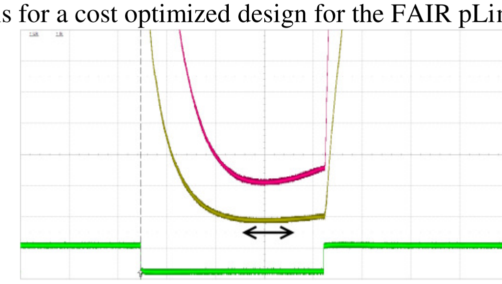

Figure 13: Vertical zoom of Fig. 12 (200 µs/div).

As next step, the circulator will be connected to the klystron and tested up to nominal power. The cavity load conditions will be simulated by waveguides of different lengths, combined with a short circuit lid. We will check the isolation performance of the waveguide couplers for the reflected power, too. Finally we prepare to exercise the prototype CH cavity in the shielded area.

CONCLUSION

The klystron and cavity test stand in GSI is progressing. We prepare for the CH-cavity tests.

REFERENCES

[1] J. Lesrel, et. al. “RF Power Systems for the FAIR Proton Linac”, LINAC2014, Geneva, Sept. 2014, MOPP078.

[2] K. Hanke et. al. “Status of Linac 4 project at CERN”, IPAC 2010, Kyoto, Japan, p. 702-704.