RF POWER SYSTEMS FOR THE FAIR PROTON LINAC

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Abstract

In the framework of collaboration between the FAIR project, GSI, and CNRS, the IPNO lab is in charge of providing the high power RF components for a cavity test stand and for the planned FAIR proton Linac. This Linac will be connected to the existing GSI synchrotron SIS18 for serving as an injector for the new FAIR facility.

The 70 MeV FAIR proton Linac design contains a 3 MeV RFQ, and a DTL based on Cross-bar H-mode cavities (CH). It will operate with pulsed RF at 325.224 MHz with a width of 200 µs and a repetition rate of 4 Hz. The planned RF systems of the proton Linac will be presented as well as the description of the test stand.

The first power test results are obtained with a Thales klystron developed jointly with CNRS. Three solid state amplifiers made by SigmaPhi Electronics for the bunchers will also be described in this paper.

INTRODUCTION

The FAIR proton linac [1, 2, 3] has to provide the primary proton beam for the production of antiprotons, and will be connected to the existing GSI synchrotron SIS18.

This Linac will deliver a 70 MeV beam with 70 mA current and will operate with a pulsed RF signal at 325.224 MHz with a width of 200 µs and a repetition rate of 4 Hz. The proton Linac will consist of a RFQ and 6 DTL based on Cross-bar H-mode cavities (CH).

Three bunchers are planned for the linac. Each acceleration cavity will be fed by a single high power RF system. Its conceptual layout is shown in Fig. 1.

The RF power systems of the proton linac are composed to 7 klystrons and 3 solid state amplifiers for bunchers, and also the waveguides and coaxial components (circulators, RF loads, couplers measurements, arc detector).

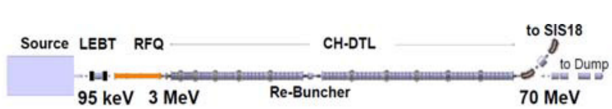

Figure 1: Layout of FAIR proton Linac.

The collaboration between the FAIR project, GSI, and CNRS began in 2010. The IPNO lab participated in the installation of the test stand at GSI, which consists of a klystron, its modulator and all components for the CH cavities test in a bunker. Meanwhile IPNO and THALES (TED) developed a klystron at 352.224 MHz with 3.1 MW peak.

KLYSTRON

The klystron developed in collaboration with THALES and IPNO is shown in Fig. 2. The gun is a diode type. The interaction structure has 5 cavities with the 3rd one operating close to the second harmonic. The output cavity is coupled to a coaxial window and a full height WR2300 waveguide transition. The collector and the body are at ground potential. The electromagnet consists of discrete water-cooled coils and is integrated with the klystron into a supporting frame. The tube operates in horizontal position and is equipped with a CERN type oil tank, and a built-in X-ray shielding. The high voltage module of the heater power supply is integrated into the oil tank.

Figure 2: The THALES klystron TH2181.

The klystron has been successfully tested, with a fast conditioning, and achieved performances are in agreement with predictions.

The klystron delivers 3.2 MW output peak power at saturation, with an efficiency of 52%. The cathode voltage and beam current are 115kV and 53A respectively. The corresponding beam perveance is 1.36 10^{-6} $AV^{-1.5}$.

The input power required to saturate the tube is 150 W, or a gain of 43.3 dB. The power transfer curve is given in figure 3. It is free of discontinuities and the power linearity is lower than 200 kW peak between 20% and 80% of saturated output power. The phase linearity is around 2 degree.

The gain variation is 0.16 dB over ± 0.75 MHz at -1dB below saturation (or 2.5 MW). The corresponding phase change is 92 °, which leads to a group delay of 170ns. The sensitivity of the output power and the input-output phase versus cathode voltage, are respectively 0.07 dB / kV and 6.4 ° / kV.

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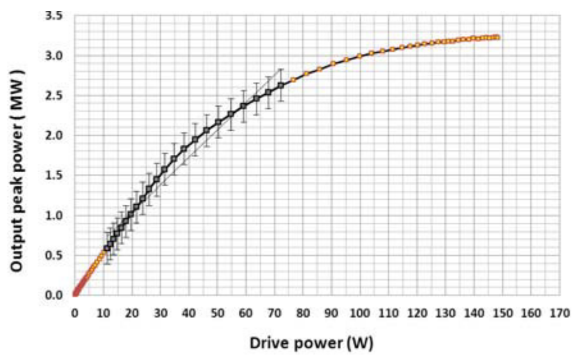

Figure 3: Power transfer curve @115kV 10 Hz 200 µs.

The test stand consists of a klystron and its modulator and all components for the CH test cavities in a bunker (see Fig. 4).

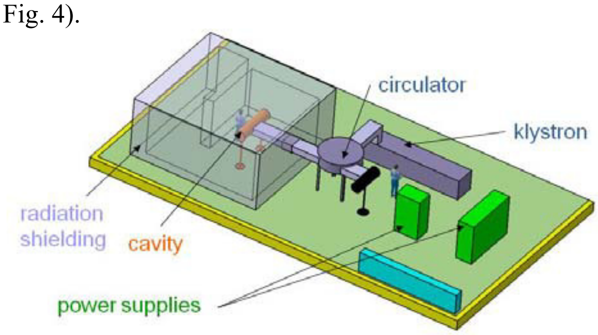

Figure 4: Layout to the test stand at GSI.

This first klystron is installed on the test stand at GSI.
In the near future a call of tender for the klystron modulators should be published, meantime CERN was asked to lend a modulator of LINAC IV type to perform the first tests on cavity. Desired characteristics for the modulator are summarized in table 1.

Table 1: Modulator Main Requirements

Modulator main requirements	Values
Repetition frequency	5 Hz
Pulse duration	220 µs
High Voltage	120 kV
High Current	55 A
Ripple on the flat top	2%
Reverse voltage	20 kV
Over shot voltage	10 kV
Rise and fall time	20 µs

At each klystron output a circulator is inserted together with an RF load to handle the reflected cavity power. All 7 RF loads made by the company AFT are already delivered (see Fig. 5); they are able to absorb all the power delivered by the klystron.

Figure 5: 7 AFT RF loads.

For the test stand, one AFT circulator was installed and all waveguides and measurement couplers are operational.

45 KW AMPLIFIERS

The company SigmaPhi Electronics has delivered three amplifiers for the bunchers at GSI. The operating frequency is 325.224 MHz with pulse duration of 200 µs at 5 Hz.

Each 45 kW amplifier is made of 2x8 RF modules 3 kW divided into 2x4 slices. Each group of 4 slices produces 24 kW. A final mix output combiner achieves 45 kW. The power supplies and amplifier modules are located in the left side bay. The right bay contains the electrical distribution, control and monitoring and also the driver (see Fig. 6).

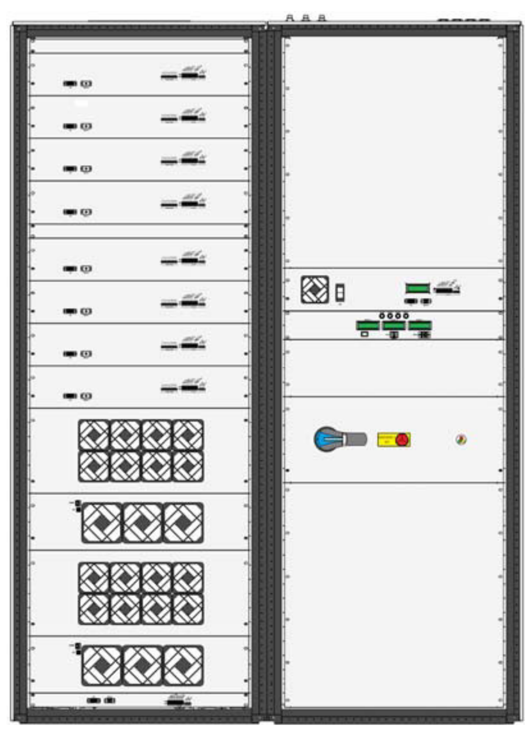

Figure 6: The SigmaPhi Electronics 45 kW amplifier.

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The system is based on a 3 kW basic RF module, which is itself based on 4 LD-MOS pallets of the most recent generation capable of delivering up to 1000W max pulsed power and 750 W routine pulsed power. The RF input power is split to feed the 16 transistor modules whose output power is in turn combined into high level by RF combiners designed for this purpose.

The three power amplifiers have been tested successfully in SigmaPhi Electronics, the results are consistent with the requests. Table 2 shows the desired and the measured characteristics.

Table 2: Desired and Measured Characteristics of SigmaPhi Electronics 45 kW Amplifier

characteristics	desired	measured
bandwidth	±1 MHz@1dB	±1 MHz@0.1dB
Output Power	45 kW	46.5 kW
Pulse duration	250 µs	500µs
Duty cycle	0.125%	1.5%
RF rise time	< 10 µs	<100 ns
Linearity gain	± 1.5 dB	± 1.2 dB
Linearity phase	10 °	4 °
Noise	> 60 dBc	>60 dBc
Harmonics	> 50 dBc	> 49 dBc (H2) > 53 dBc (H3)

Figures 7 and 8 show the variation of gain and phase versus input power for the tree amplifiers. The curves are very similar with gain linearity and phase linearity better than specifications. Figure 9 shows the RF pulse itself @ 45 kW.

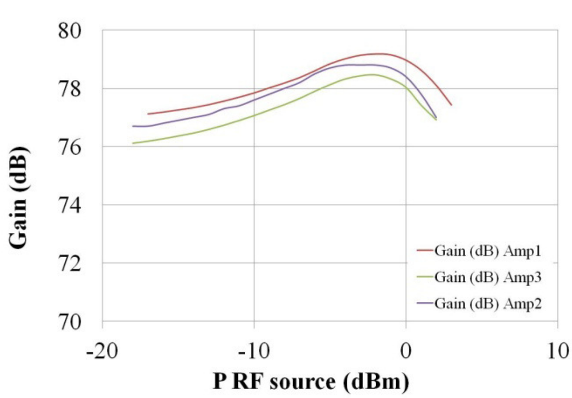

Figure 7: Gain vs input power.

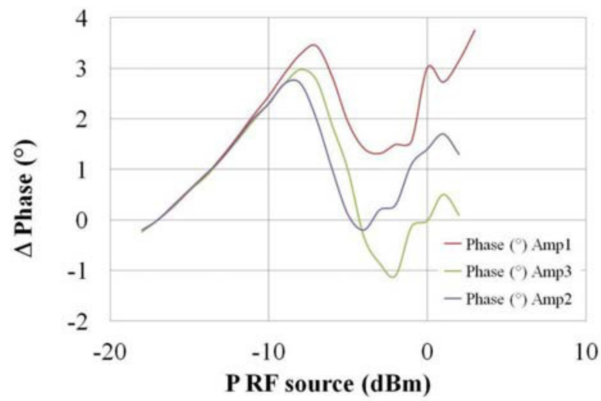

Figure 8: Phase variation vs input power.

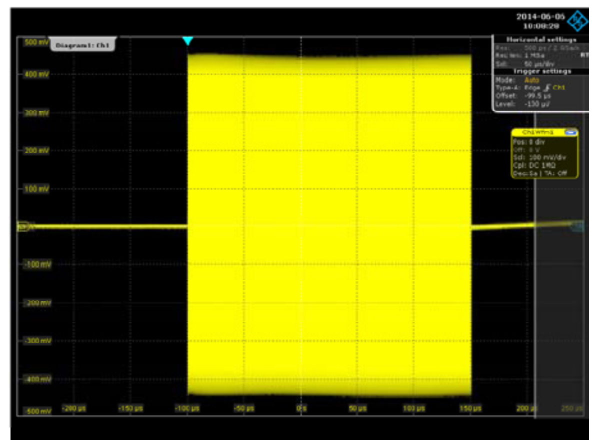

Figure 9: The RF pulse (50 µs/div) @ 45 kW.

CONCLUSION

The main choice of RF components to power the proton linac for FAIR have been made and some components are under production. The first tests of cavities on the test stand will be made shortly and the entire RF power will be delivered on time. The collaborations between laboratories as well as with the industry are profitable.

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