NEW 1MW 704MHZ RF TEST STAND AT CEA-SACLAY

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Abstract

In the frame of the European CARE/HIPPI programme, superconducting accelerating cavities for pulsed proton injectors are developed. Qualification of these 704 MHz RF structures fully equipped (housed in a helium tank, with tuning system and power coupler), requires to perform high power tests in the existing horizontal cryostat CryHoLab. During the last years, CEA-Saclay built and ordered the necessary RF equipments to make such a platform for high power RF tests in a cryogenic environment available to the partners in HIPPI and later on to any other interested teams. The main components of the RF test stand (95 kV-275kVA DC High Voltage Power Supply, 50Hz modulator and 1MW 704.4MHz RF klystron amplifier) are now installed and tested. In this paper, we present the different components with a focus on the new design of the hard tube modulator to match the new specifications and the compatibility with the floating HVPS, the results of the HV and RF measurements performed.

INTRODUCTION

CEA built and ordered the necessary RF equipments to make a platform for high power tests in a cryogenic environment available. Only few similar platforms are existing in Europe (at CERN for tests at 352 and 400 MHz, at DESY and BESSY for tests at 1300 MHz) but not any was equipped to perform RF power tests at 704 MHz. This latter frequency was chosen for the medium and high energy parts of the sc linac CERN-SPL-II [1]. With such an equipment, qualification of the main components (sc cavities of various beta's, power couplers, tuning systems and compensation scheme, …) of sc linacs for high intensity pulsed proton beams are now possible.

The new components [2] were installed besides already existing 1300MHz klystron and 700MHz IOT (Fig. 1). Firsts measurements were performed in 2007, and most of the components were qualified in terms of peak power and pulse length, but the HVPS rectifier which showed breakdowns. Corrective modifications are undertaken.

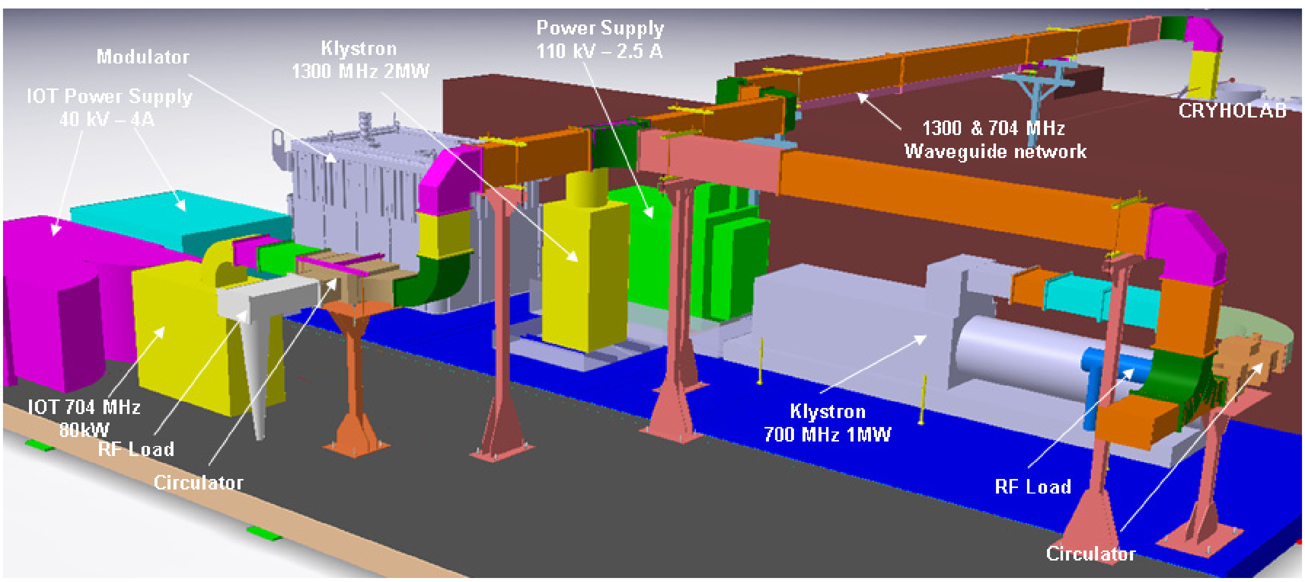

Figure 1: General layout of the RF test stand

HV MODULATOR AND KLYSTRON

The HV modulator is of hard-tube pulse generator type, designed and fabricated within a collaboration between CEA/DAPNIA and IN2P3/LAL, and used to drive a Thomson klystron TH2086 (peak RF power: 2MW, pulse length: 1ms, repetition rate: 10Hz). In order to match the new requirements of the 704 MHz klystron as well, a major upgrade has been undertaken since the frequency repetition and the pulse length were not compatible with the old design anymore. The new electronic scheme of a modulator matching these requirements is shown in Fig. 2. The main modifications [3] consisted of the addition of one HV feedthrough to connect the floating HVPS and upgrade of the 50Ohm protection resistor dissipation rating. Moreover, a reverse diode connected to the negative pole avoids klystron voltage inversion [4].

Table 1: Modulator main parameters

Peak output power	5MW
Max Ioutput pulse	55A
Max Voutput pulse	96kV
Pulse width	2.2ms@20A, 1.1ms@55A
Max rep. rate	50Hz@20A, 10Hz@55A
Flat top voltage ripple	200Vpp@95kV

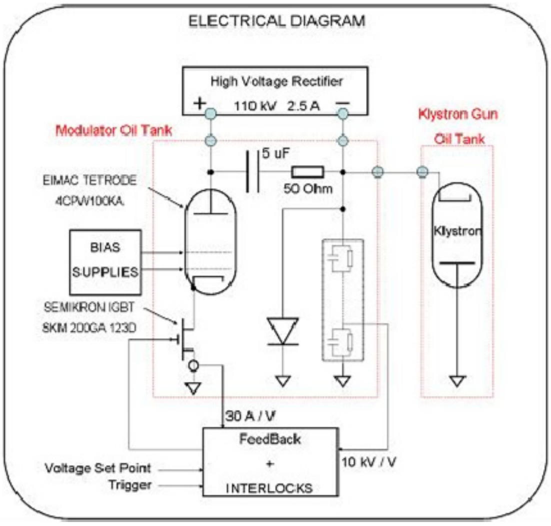

Figure 2: Electrical diagram of HV Modulator

The 704MHz VPK 7952C Klystron is a high power tube developed by CPI for scientific applications. It is driven by the modulator in a pulse cathode modulation mode.

Table 2: Main parameters of the klystron

Center Frequency [MHz]	704
Frequency band @ -1dB [MHz]	+/- 1
Peak Output power [kW]	1000
Average Output power [kW]	100
RF Drive power [W]	10
Gain [dB]	50
Max. Cathode Voltage [kVdc]	95
Max. Beam current [Adc]	17
RF Leakage [mW/cm2]	0.2
X rad. @ 1m (public exp.) [mS/hr]	0.5

HV AND RF TESTS

In order to safely increase the duty cycle up to 10%, great care must be taken to avoid an excess of dissipating power in the tetrode and the IGBT, hence the tetrode screen grid voltage has to be carefully optimized (Fig. 3).

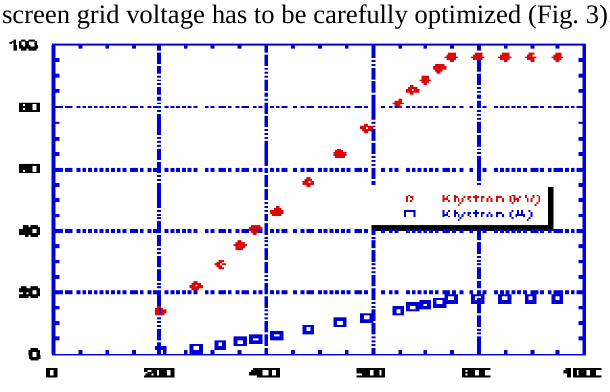

Figure 3: I-V modulator output vs tetrode screen grid voltage with V(anode_tetrode)=5kV and V(drain_IGBT)=25V

The first tests of the klystron were performed without RF drive power. Operation started at a low repetition rate of 0.3Hz and 300μs pulse width. The klystron was brought up to more than 96kV and the maximum klystron current was 18A.

All the RF tests were done with a 150KW average power water cooled load, connected to the klystron output through a bi-directional coupler.

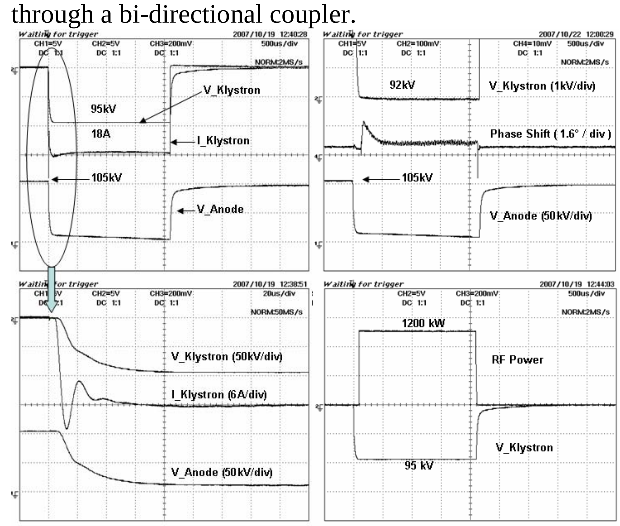

Figure 4: Oscilloscope signals with HV pulse=2.2 ms & RF pulse=2.0 ms

From the measurements (Fig. 4), the HV ripple is lower than 100V in the first 300μs and lower than 10V above 300μs, which is in good agreement with the klystron flat top phase shift measurement (klystron phase shift=10°/kV at 92kV). The undershoot appearing when zooming the klystron current signal trace (left oscillographs in Fig. 4) is due to the 5nF stray capacitors of the three 7m long HV cables , HVPS and klystron heater transformer.

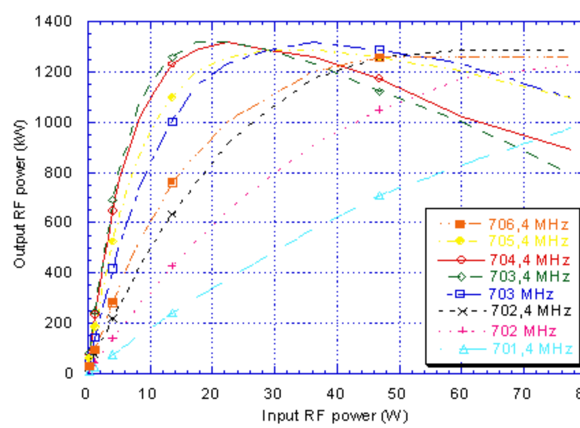

Figure 5: RF power vs drive power at reduced rep. rate

The first RF tests were performed at a low pulse length and repetition rate. With the settings Vkly = 96 kV and Ikly = 18 A, an output RF power over 1MW peak was measured from 701.4MHz to 706.4MHz with a drive power between 10 to 80W (Fig. 5). Finally, the nominal 50Hz repetition rate and 2ms RF pulse length were achieved with the same settings.

HVPS TROUBLESHOOTING

The 110kV 2.5A HVPS consist of a six-phases rectifier, controlled on 400V three-phases primary side by a thyristor bridge (SEMIKRON SKKT 500/14E). The step-up transformer is a triangle/star type with a grounded screen on the primary side. Each leg of the rectifier consist of 125 controlled avalanche diodes (SEMIKRON SKNa 20/17) giving large margin on reverse voltage and over current protection.

Unfortunately, a rectifier leg was shorted after few hours of operation at full voltage and high repetition rate, without any evidence of external HV breakdown (modulator, klystron). After a first reparation, the same failure appeared on the same negative side of the rectifier, convincing us of an unexpected behaviour due to the pulsed operation. In order to study this problem in a safe way, low level measurements on the HVPS were performed. The star connection on the transformer HV side was excited by the modulator pulse, and the excitation frequency was increased. When the frequency was close to 50Hz, un-damped oscillations occurred. So, depending on the modulator repetition rate, dangerous HV resonance can grow. Adding a 47kOhm resistor between the neutral and the DC outputs through 2nF by-pass capacitors damped these oscillations.

Moreover, these measurements allowed us to get accurate values of transformer mutual inductances, stray inductances and stray capacitors. SPICE simulations showed the possible trouble with the diodes. During the fast switch on time of the klystron pulse (100kV/10us), a 10A reverse current flows through the negative leg of the rectifier (charge of the 2nF transformer stray capacitor). As the recovery time of the diodes is about 10us (Fig. 6) with a dispersion of few microseconds, some diodes are blocked before others, pushing the blocked diodes in the avalanche zone (2.6kV@3A measured, 3kV@10A estimated), giving a dangerous 50mJ extra energy dissipation per pulse.

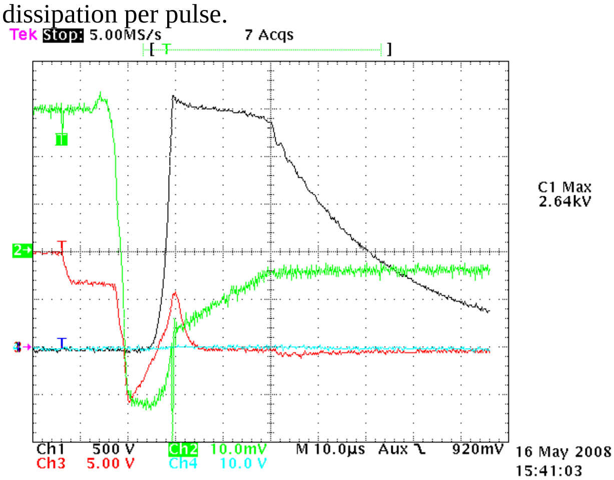

Figure 6 : Diode reverse characteristics. C1 is the cathode voltage (500V/div), C2 is the diode current (1A/div) , 3A to -3A step then 8µs recovery and rise into the avalanche breakdown – C3 is the IGBT test circuit gate voltage.

To solve the problem, one can share the diode reverse voltage with parallel capacitors, but experiment show that at least 100nF is needed (rated to 2kV) which are too large to be installed inside the transformer oil tank. The chosen solution is to replace the avalanche diodes by fast recovery ones (TRR<1us) with 10nF parallel capacitors, limiting to 1kV the maximum diode reverse voltage (assuming 10A and 1us reverse current pulse), so avoiding the avalanche operation and its associated over heating. The damping circuit was already installed on the transformer neutral point and its efficiency was successfully measured up to 30kV (limited by the Tektronix HV probes) and tested at full voltage and low repetition rate (in order to avoid the rectifier diodes to be destroyed).

CONCLUSION

The HIPPI power test stand is close to be ready. The modulator can perform 95kV 20A 2ms pulse with very low flat top ripple. The klystron can deliver the 1MW peak power with enough margins in the 702MHz to 706MHz bandwidth. The circulator was tested at full power, only pressurized with dry nitrogen, but connected to a matched load. The tests on a sliding short can start now, but the operation at full repetition rate will be done as soon as the HVPS modifications will be made.

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