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STATUS AND COMMISSIONING OF THE FIRST X-BAND RF SOURCE OF THE TEX FACILITY

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Abstract

In 2021 started the commissioning of the TEX (TEst stand for X-band) facility at the Frascati National laboratories of INFN. This facility has been founded in the framework of the LATINO (Laboratory in Advanced Technologies for INnOvation) project. The current facility layout includes a high power X-band (11.994 GHz) Radiofrequency (RF) source, realized in collaboration with CERN, which will be used for validation and development of the X-band RF high gradient technology in view of the EuPRAXIA@SPARC_LAB project. The RF source is based on a CPI VKX8311 Klystron and a solid state ScandiNova k400 modulator to generate a maximum RF output power of 50 MW at 50 Hz, that will be mainly used for accelerating structure conditioning and waveguide components testing. In this paper the layout, the installation, commissioning and stability measurements of this source are described in detail. The test stand will be soon operative and ready to test the first X-band accelerating structure prototype.

INTRODUCTION

The X-band (11.994 GHz) was chosen as the basic RF technology for the realization of the booster of the EuPRAXIA@SPARC_LAB Linac [1, 2]. This project aims at constructing a free electron laser source based on a normal conducting RF Linac and a plasma acceleration module to generate a high brightness 1 GeV electron beam. The X-band is at present the most advanced RF technology, with demonstrated capability of providing accelerating gradients up to 100 MV/m and beyond. Achieving top level performances requires great expertise in the RF design, fabrication techniques and conditioning procedures. For this reason, as part of the preparatory activities related to the EuPRAXIA@SPARC_LAB project, a high-power test stand for X-band (TEX) has been commissioned at INFN Frascati National Laboratory. The purpose of this source is mainly to test and condition RF devices and high gradient accelerating structures but it will also allow R&D activities on LLRF systems, beam diagnostics, vacuum and control system. Its design has been done in collaboration with CERN and so the facility will be also used to test and condition structures for the CLIC project.

Through the LATINO project [3], it will be also accessible to external users, including national and international laboratories and companies. This is a project funded by the government of "Regione Lazio" aimed at promoting and increasing the technology transfer between research centres of excellence and the surrounding economic framework. In November 2021 started the commissioning of the TEX RF source with the site acceptance test of the modulator and the commissioning of the LLRF and Control system. The TEX Layout and the main results obtained during these preliminary tests are shown below.

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TEX FACILITY LAYOUT

TEX is located at the building 7 of the Frascati national laboratory of INFN, that has been completely refurbished. As reported in [4], the TEX facility includes a control room, a rack room, the X-band source cage and a concrete bunker in which the RF devices and high gradient structures to be tested will be installed. The rack room hosts all the ion pumps controllers, the rack of the EPICS control system and the LLRF system.

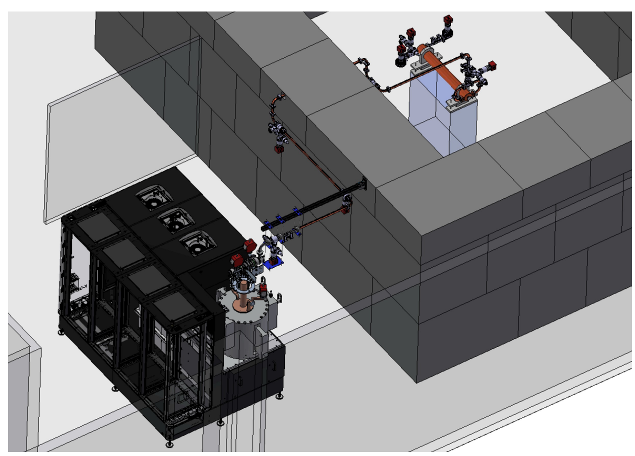

Figure 1: TEX RF Source layout.

The TEX RF power source layout is based on a Solid State Scandinova K400 modulator and a VKX8311A Klystron which was given to us by CERN on permanent loan. A sketch of the current TEX layout is reported in Fig. 1. At full specifications it will be able to produce RF pulses of 50 MW long 1.5 μs with a rep rate of 50 Hz. Table 1 shows the main parameters of the RF Source.

The pulsed modulator (Fig. 2) is capable to reach 430 kV with a maximum average power of 50 kW. The RF pulse at the klystron input is preamplified by a solid state drive

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Table 1: RF Source Main Parameters

Parameter	Unit	Value
Frequency	MHz	11 994
Bandwidth	MHz	100
Peak RF Power	MW	50
Average RF Power	kW	3.75
RF Pulse length	μs	1.5
Repetition Rate	Hz	50
Voltage at the cathode	kV	430
Klystron Current	A	330
Gain	dB	48
Efficiency	%	48
HV pulse length	μs	3.5

amplifier model AM61-12S-66-61PR4 (manufactured by Microwave Amps Ltd) up to 1.2 kW. The Low-Level RF is based on the Libera LLRF, a commercial system realized by Instrumentation Technologies. This system works at the American S-band frequency (2856 MHz) and it has been adapted to work at the European X-band 11994 MHz by means of an Up/Down Converter developed at our laboratory together with the RF reference generation and distribution system. A detailed description of the TEX LLRF system, together with the firsts measurements performed during the SAT of the source, are reported in [5, 6].

At the klystron output a WR90 waveguide of total length approximately equal to 9 m transports the high power pulses inside a concrete shielded bunker, in which the RF device or the high gradient accelerating structure to be tested will be installed. The waveguides operate in extremely high vacuum, with a pressure lower than 10^{-10}mbar to avoid internal arcs due to the high peak power conveyed to the accelerating structures. This vacuum pressure is obtained by using 5 non evaporable getter (NEG) ion pumps plus an additional ion pump placed at the klystron output. The RF signals (Forward and Reverse) are sampled by means of two directional couplers placed at the klyston output and at the device under test (DUT) input. An additional directional coupler in air has been installed between the RF driver output and the klystron input to monitor the power at the tube input.

In a second phase of the development of this station, the installation of an BOC (Barrel Open Cavity) pulse compressor along the waveguide is foreseen to increase the available power of the source and being able to supply more than one structures at the same time.

SOURCE COMMISSIONING

In September 2021 the civil work for the building refurbishment ended and started the RF Source commissioning. The Driver amplifier has been integrated in the modulator rack and the klystron has been installed into the modulator tank. Then, the solenoid electromagnet, the source cooling system have been wired and the output waveguide of the klystron has been connected to the waveguide system termi-

Figure 2: RF Source of the TEX facility.

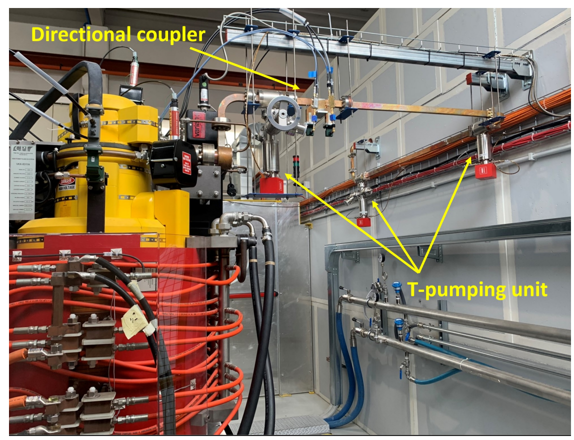

Figure 3: Current waveguide layout at the klystron output.

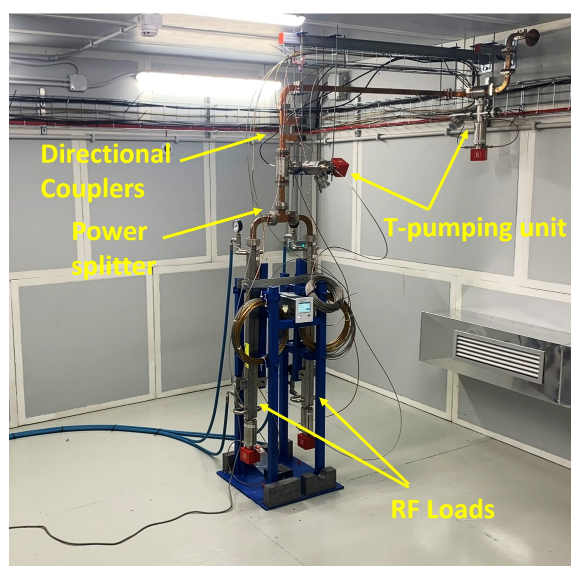

Figure 4: Current waveguide layout inside the bunker.

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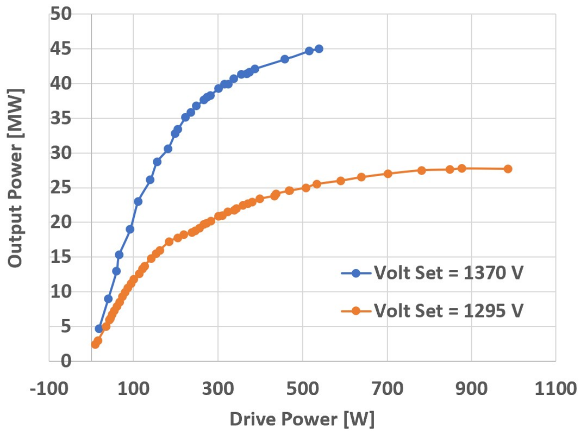

Figure 5: Output power versus input power curves of the klystron.

nated on two high power RF loads with a splitter. The current configuration of the waveguide system at the klystron output and inside the bunker is shown in Figs. 3 and 4. Before the NEG activation the waveguide system from the klystron RF window up to the loads has undergone a soft baking with heating tapers wrapped along the entire length of the waveguide itself. Baking was carried out continuously at 140°C for 4 days, bringing the guide, once cooled, to a final pressure lower than 10^{-10}mbar. This procedure made it possible to speed up the subsequent conditioning operation. In parallel to this activity the modulator interface has been integrated in the EPICS control system framework and the Libera LLRF system with the Up/Down converter have been installed. More information about the TEX control system and its commissioning can be found in [7]. The cables connecting the directional couplers output to the LLRF System have been calibrated by using both power meter and vector analyzer measurements.
After all the subsystems installation, the high voltage modulator Site Acceptance Test (SAT) has started. During this test the modulator has been tuned to obtain the required design parameters. At the end the procedures the stability and flatness of the modulator pulse were accurately measured with a measurement system consisting of an oscilloscope, a differential amplifier and an isolation transformer. The measured pulse flatness was about $\pm 1.5\%$ and the pulsed to pulse stability was 14ppm.

To guarantee a safe conditioning of the klystron and waveguides system an automatic procedure has been developed and integrated in the EPICS control system. This routine allows handling the different interlocks from the modulator, vacuum and RF system and gradually increase the RF feedback set level, of the klystron Output signal, following a sigmoidal curve. After a breakdown, it decrease the power and turns on the RF trigger after vacuum restoring. It's still being tested an algorithm for managing cluster of discharges and a system of real time detection of breakdown on RF signals based on machine learning [7]. Moreover, an EPICS based Telegram integration has been also deployed for the interlocks and alarms handling of the RF Source, as reported in [8]. During these preliminary tests, performed during the source SAT, the Output characteristic curve of the klystron have been reconstructed for a pulse length of 150 ns by using the directional couplers FWD signals at the input and at the output of the tube. A peak output power of 48 MW with a 150 ns pulse length at a 50 Hz repetition rate has been reached. The curves, obtained with two different voltage set of the modulator, are reported in Fig. 5. Before the end of the SAT, some preliminary measurements in terms of amplitude and phase jitter of the klystron forward output has been performed trough the LLRF System, measuring 0.04% and 20.7fs respectively and are reported in [6].

CONCLUSION

By the end of 2021 and beginning of 2022 the TEX Facility has been successfully commissioned and all the subsystems have been installed and tested. The complete waveguide system has been baked and installed up to the position of the accelerating structure prototype inside the concrete shielded bunker. The performances of the RF source in terms of jitter and Pulse to Pulse amplitude stability have been measured during the modulator SAT, with a peak output power of 48 MW, 150 ns pulse length at 50 Hz. After these encouraging results, the test station will became fully operative and ready to test the first EuPRAXIA@SPARC_LAB accelerating structure prototype by the end of 2022. An upgrade of the facility is currently under study with the possibility of installing a second X-band RF source to double the available testing stations and the conditioning capability of TEX.

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