High-Gradient RF laboratory at IFIC for medical applications

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Introduction

General interest has been shown over the last years for compact and more affordable facilities for hadron-therapy. The High-Gradient (HG) know-how and technology for normal-conducting accelerating RF (Radio-Frequency) electron linac (linear accelerator) structures recently developed for projects such as CLIC (CERN), has raised the achievable accelerating gradient from 20-30 MV/m up to 100-120 MV/m. This gain has come through a better understanding of the high-power RF vacuum arcs or breakdowns (BD) phenomena, the development of quantitative HG RF design methods and refinements in fabrication techniques. This can allow for more compact linacs also for protons, which is potentially important in the new trend in hadron-therapy of using linacs able to provide protons of 70-230 MeV or light ions of 100-400 MeV/u. Linacs are of particular interest for medical applications because they can provide a high degree of flexibility for treatment, such as running at 100-400 Hz pulse rate and pulse-to-pulse beam energy (and intensity) variations. This kind of accelerator is very well suited to treat moving organs with 4D multi-painting spot scanning technique. Project studies like TULIP [1] are taking advantage of these developments and pursuing medical linacs of reduced size.

HG operation, which is carried out under ultra-high vacuum conditions (~10^{-9} mbar), is limited by the BD phenomena and is characterized by the BD-Rate (BDR) or number of BD per pulse and meter. New fresh structures initially operate at a reduced performance and must be conditioned through extended high-power RF operation until the maximum operational gradient is reached. This process is a time consuming, and consequently costly task (> $350 \cdot 10^6$ pulses) which is important to understand and reduce. The IFIC HG-RF laboratory is designed to host a high-power and high-repetition rate facility for testing S-Band (2.9985 GHz) normal-conducting RF structures. This facility will allow the development, RF conditioning and studies of the BD phenomena in HG structures.

Design of the high-power RF system of the IFIC High-Gradient laboratory

The design of the laboratory has been made through a collaboration between the IFIC and the CLIC RF group at CERN. The layout is inspired by the scheme of the Xbox-3 test facility [2] at CERN, and it has been adapted to S-Band frequency. The system implements two test slots and layout with all the elementary components is shown in Fig. 1.

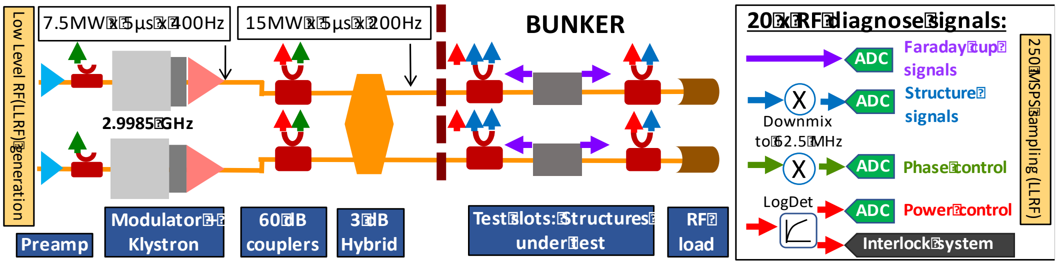

Figure 1: Layout of the system with all the elementary components and the RF signals essential for the stand and the studies, from RF generation to signal diagnosis.

The system makes use of two pulsed S-Band klystrons, powered by two solid-state modulators. In a first step, the klystrons RF inputs are driven from a preamplifier stage consisting on a 400 W solid-state amplifier with a gain of ~56 dB. The input for these amplifiers is a 5 µs length pulsed RF signal of 2.9985 GHz generated by the Low-Level RF (LLRF) system. The klystrons are able to provide an RF peak power of 7.5 MW with a pulse length of up to 5 µs and a repetition rate of up to 400 Hz. The output power of both klystrons is combined in a 3 dB hybrid to reach a power up to 15 MW alternately in any of the two lines depending on the relative phase between the two incoming

RF waves, at the cost of reducing the repetition rate by a half, ie. 200 Hz. The RF power of each line is driven through WR-284 waveguides to the structures under test, installed inside the bunker, which will be equipped with the experimental setup required for BD studies. The RF power amplitude of each klystron can be controlled pulse to pulse, which offers the required flexibility to test different prototype designs or structures that present different conditioning states. Directional couplers are used to diagnose the forward and reflected RF signals into the waveguide system and structure under test.

Design of the LLRF and diagnostics system

The facility will be controlled by a National Instruments [3] PXI real-time system in charge of the LLRF generation, the acquisition of the RF diagnoses signals, the signal processing, the trigger control and interlock of the hardware. Two PXI RF generators provide the amplitude and phase modulated RF pulse which drives the preamplifiers, which in turn drive the klystrons. A downmixing system moves the RF signals down to 62.5 MHz and the 250 MSPS ADCs and FPGA modules in the PXI system allow for a real-time IQ demodulation and the data processing needed for BD detection. Some signals are also used to perform a reliable closed loop control of the input power to the structure and of the signals phase. The reflected power from the structure towards the klystron, caused by the BDs, requires a robust interlock system in order to avoid damage to the structure due to continuous BDs. Excessive high reflection over many pulses could also damage the waveguide components and the klystron's output window. In the interlock system, which will be made of RF logarithmic detectors, reliability and redundancy are compulsory. Finally, the signals of the faraday cups placed in the upstream and downstream directions along the structure's beam axis to measure dark currents are also digitized.

The diagnostics (Fig. 2) and control system are very configurable in order to grant flexibility for different types of experiments. Threshold detection on the reflected signal from the structure and the dark current signals, measured from the Faraday cups, are used to establish if a BD has occurred. In addition, the ion gauge readouts monitor the pressure level in the vicinity of the structure. The RF conditioning process will follow that of the Xbox-3 using the same algorithm described in [4]: the input power in the structure is raised in a controlled manner, while maintaining a BDR below 3x10^{-5}. The acquired data will be analyzed off-line to seek where inside the structure the BD occurred using similar data analysis methods to those used for the Xbox-3 [5]. They are based on the time difference between the transmitted and reflected signals and the incident and reflected signals respectively. This analysis is essential for the evaluation of the performance of the HG structure, since it is required that BDs are distributed uniformly along all the cells.

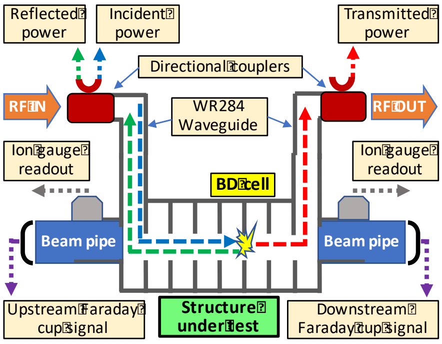

Figure 2: Layout of the device under test and the diagnostic systems. The arrows show the signals readout by the acquisition system.

Conclusions

High-Gradient RF technology offers the possibility of constructing compact HG linacs for medical applications. Their performance is limited by the occurrences of BDs and the described test facility will permit carrying out an extensive experimental program for testing HG accelerating structures and performing breakdown phenomenology studies for S-Band HG linacs. The goals are improve the performance and lower the cost of the RF structures.

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References

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