INSTRUMENTATION FOR THE 12 GHz STAND-ALONE TEST-STAND TO TEST CLIC ACCELERATION STRUCTURES*

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Abstract

Vacuum breakdown is one of the primary limitations in the design and construction of high energy accelerators operating with warm accelerating structures (ACS) such as the CLIC linear collider because the mechanisms that cause the breakdown are still a mystery. The ongoing experimental work is trying to benchmark the theoretical models focusing on the physics of vacuum breakdown which is responsible for the observed discharges. The CLIC collaboration is preparing a dedicated 12 GHz test-stand to validate feasibility of different models of accelerating structures and observe the characteristics of the RF discharges and their eroding effects on the ACS. The instrumentation for the test-stand must be versatile and allow for the conditioning of the ACS with measurements of the breakdown rates at different power levels as well as detection of the dark current and light emission directly relevant to breakdown physics. For that purpose we are developing 2 instruments. A pepper-pot chamber with an external magnetic spectrometer for measurement of the spatial and energy distributions of the electrons emitted from the ACS and an optical laser system for probing the ACS to observe the effect of a discharge on the transmitted light.

INTRODUCTION

The knowledge of physical processes inside the ACS during RF pulse and especially during breakdowns is limited. We know that electrons are field-emitted from high field regions under normal operation conditions. This leads to the emission of dark current during the pulse. The electrons hit the cavity wall releasing gas. Out-gassed molecules are emitted with eV speeds, but after first collision they are thermalized and do not normally escape from the RF structure increasing the pressure inside the cavity. This can create fast beam-ion instabilities which can have destabilizing effects on the beam.

Field-emitted electrons can however be accelerated by the RF pulse and leave the structure with maximum kinetic energy given by the size of the ACS and accelerating gradient. The situation during breakdown events is even more complicated, leading to order of magnitude higher currents detected outside the structure. In case of a breakdown the cavity material experiences heavy surface evaporation and can be ionized due to thermal ionization or bombardment from field-emitted electrons. Part of the electrons are accelerated in the RF field and the remaining ions can explode under the influence of their mutual Coulomb repulsion. This effect has been reported in [2].

We plan to design the diagnostic system around the 12 GHz stand-alone test-stand dedicated to breakdown physics and breakdown onset research. We want to build it in such a way as to be able to perform several measurements in parallel, specialized on the detection of dark current, electron and ion distribution in space and energy and dynamic vacuum conditions.

DESIGN

The X-Band Klystron Test Stand

Considering the vital and absolute necessity of a sufficient number of high power tests of structures to validate the feasibility of the CLIC technology, a new stand-alone power source operated independently of the main facility at CTF3 is being constructed by the CLIC collaboration at CERN [1]. It consists of a single 12 GHz klystron feeding the structure under test after a pulse compression. The general layout of the 12 GHz test stand is presented in Figure 1. The main parameters of the test-stand can be found in Table 1.

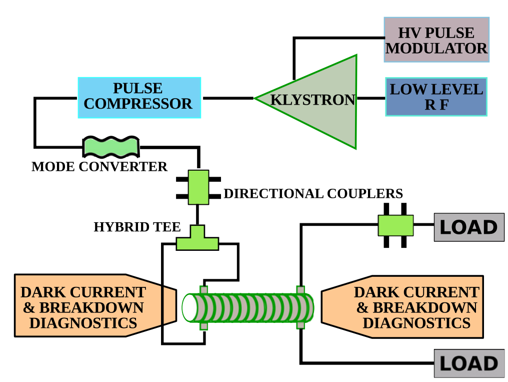

Figure 1: The klystron will deliver a peak RF power of 50 MW at 11.9942 GHz. The RF pulse is compressed and amplitude- and phase-modulated by the low level RF system. The RF power is transferred to the accelerating structure test area for conditioning and diagnostics.

Diagnostics

The accelerating structure will receive RF power from the klystron and the incident, reflected and transmitted

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Table 1: The main parameters of the high voltage (HV) pulse modulator and X-band klystron used for the test-stand.

KLYSTRON	
Frequency	11.9942 GHz
Peak power	50 MW
Repetition rate	50 Hz
HV Pulse Modulator	
Type	solid state
Cathode current	335 A
Cathode voltage	450 kV
Pulse flat top	1.5μs
Repetition rate	50 Hz

power will be measured at the directional couplers (see Figure 1) with diode and I-Q detectors for amplitude and phase. This set of standard diagnostic devices will be complemented by a novel spectrometer setup in order to measure the electrons and ions that emanate from the structure [2].

Spectrometer with a pepper-pot grid

We plan to use pepper-pot grids in order to obtain the spatial information about the ejected electrons or ions within one RF pulse. The idea with a pepper-pot is that the electrons hit a plate with a number of small holes arranged in a matrix of lines and columns. The passing particles defined by this pattern form beamlets and continue further where they can be observe on e.g. viewing screen. In our design we plan to put a bending magnet directly after the pepper-pot grid to get an energy-dependent pattern on the screen behind the magnet. It is evident that the design of the hole pattern has to be adapted to the expected width of the energy bands to avoid overlap of beamlets. At the end, the viewing screen where the light spots are observed, will be read out by a camera. To allow for maximum flexibility of the system we plan to use a holder fitting several exchangeable pepper-pot grids mounted on an actuator operated by a motor with possibility to fully extract the grids from the beam. See Figure 2.

The screen will also be mounted on a linear actuator with a stepper motor which will allow to place the screen at different distances from the beam axis. The motion range will allow to put the screen in the middle of the beam axis and retract it fully out of the beam range. See Figure 3.

The diagnostic system will be terminated by a Faraday cup which will allow to measure the electron and ion currents when both screen and pepper-pot are removed. The electrode of the Faraday-cup is cut at a 45^o angle and polished, allowing reflected light from breakdown events to reach a detector mounted outside the vacuum chamber for triggering and diagnostic purposes. In Figure 4 one can see the first version of the design.

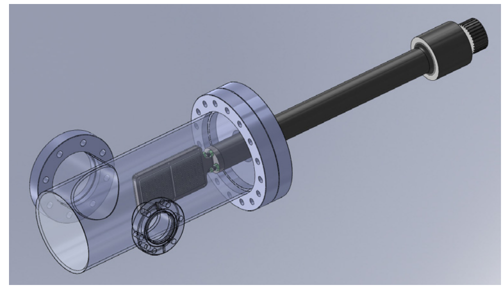

Figure 2: The vacuum chamber with 2 pepper-pot grids mounted on a linear manipulator. The grids can be fully extracted from the particle pathway.

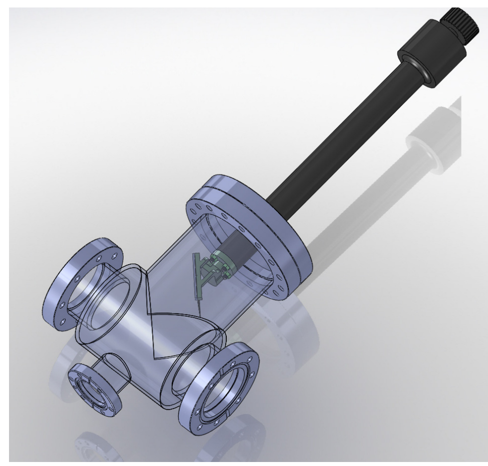

Figure 3: The vacuum chamber for the screen. The screen will be visible to the camera via a view-port at 45^o angle.

An estimate of the particle flux and resulting number of events per pulse was made. One can assume, for a non-breakdown event, that the electrons are field-emitted, then accelerated and distributed uniformly in the cell. Taking into account geometry of the setup and assuming $1 \cdot 10^{10}$ emitted electrons one can expect $6 \cdot 10^6$ of them to hit the

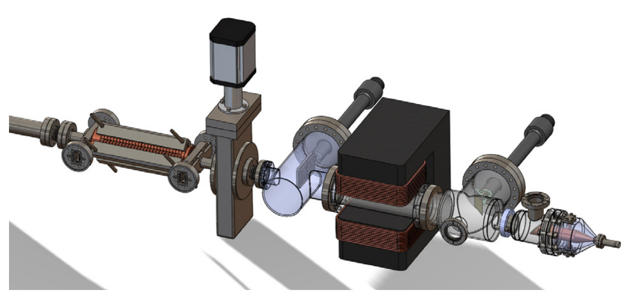

Figure 4: 3D-model of the diagnostic setup. Shown from the left are: the ACS followed by the vacuum valve connected to the chamber hosting pepper-pot grids, dipole magnet and fluorescent screen chamber with the view-port for the camera. The setup will be terminated by the Faraday cup equipped with a view-port.

pepper-pot. This flux will be reduced by the factor 10 - 20 depending on the hole pattern. With a factor 20, we get approximately $3 \cdot 10^5$ electrons passing the pepper-pot into beamlets. With a 9 by 15 hole pattern we can expect approximately 2500 electrons/beamlet/RF pulse. That is enough for spectroscopic analysis with a magnet.The expected number for breakdown events should be one order of magnitude higher.

A simplified setup containing a single pepper-pot, magnet and a screen was modeled in GEANT4 in order to investigate the optimal material and thickness of the pepper-pot absorber and the geometry of the setup. The preliminary results indicate that the best material for the absorber would be 5 mm thick tungsten. With 5 mT magnetic field we expect to observe beamlets leaving the 1.5 mm diameter hole as approximately 50 mm lines on the screen and be able to resolve almost the entire energy range from 0.5 to 20 MeV. The possibility of producing such a relatively low magnetic field with the required field uniformities ($\Delta B/B \approx 5 \times 10^{-3}$) is now under investigation. An electrostatic, parallel-plate deflector is considered as an alternative.

In Figure 5 one can see the example result from the simulation of $4{\times}10^6$ electrons generated with flat energy distribution with 5 mm-thick tungsten pepper-pot and magnet strength of 5 mT.

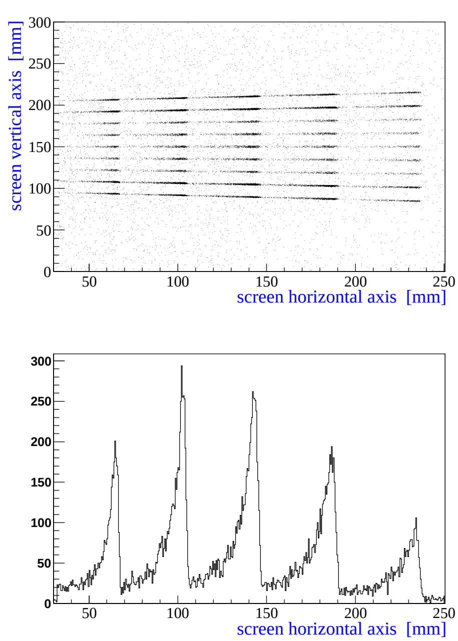

Figure 5: Pepper-pot pattern expected on the screen after the simulation of $4{\times}10^6$ electrons generated with flat energy distribution 0.5-20 MeV with 5 mm-thick tungsten pepper-pot and magnet strength of 5 mT. Top: 2D picture, bottom: projection on the horizontal axis.

Probing the dynamic vacuum with optical laser

We propose to use a mode-locked short pulse laser system consisting of a ring oscillator with amplifier and a modulator in which part of the light path is directed through the acceleration structure that contains the gas volume that we intend to diagnose. A schematic of the system is shown in Figure 6. Such a system can be analyzed using the method described in ref. [3] where a Gaussian pulse is propagated through the system of laser amplifier, modulator and the gas volume with the result that the laser pulse after one round-trip is still Gaussian within the approximations used, but the amplitude and pulse length depend on the second derivative of the absorption coefficient α on the frequency $d^2\alpha/d\omega^2$ in the gas volume, which in turn depends on the pressure [4]. This indicates that the effect is maximum in the center of an absorption line. We intend to couple a small fraction of the pulse in the ring laser onto a photodiode connected to an oscilloscope where we expect the low-pass filtered variation of the amplitude to be observable as a function of time with a bandwidth mainly limited by the round-trip time of the ring-laser. Alternatively the variation of the pulse length should be observable on an optical spectrum analyzer, albeit at lower bandwidth. The magnitude of the observables depends on the details of the gas distribution and the laser system, which need to be investigated in detail in the future.

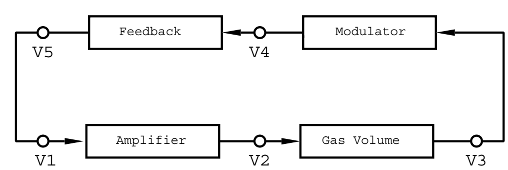

Figure 6: The conceptual setup of the ring oscillator. The gas volume in the ACS that we intend to probe is shown at the lower right.

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