Current signals and X-ray spectra analysis for a vacuum high voltage holding experiment

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- Accelerating voltage: 1 MV
- Extracted and accelerated current: 40 A
- Neutralization efficiency: 60%
- Beam power: 17 MW
- Pulse length: 1 h
- Operating gas: H, D
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Open issue: voltage holding capability in the gap between the Ion Source and the Vessel in MITICA (conditioning pressure of $10^{-5}$ Pa, typical gap of 1 m)
High Voltage Padova Test Facility

HVPTF aims:
- to support MITICA design and operation
- to test MITICA components (e.g. high voltage insulators)
- to investigate the voltage holding in vacuum as a physical phenomenon (e.g. diagnostics, large gaps)

- Stainless steel vacuum chamber (2.4 m long, Ø=1.2 m)
- 2 Cockcroft-Walton power supplies, +400 kV, -400 kV, 1 mA dc
- Vacuum pressure around 4.10^{-7} mbar
- Electrodes gap length 0-250 mm
Diagnostics

- Applied voltages, $V_+$ and $V_-$, electrode currents, $I_+$ and $I_-$ and pressure signals are sampled together at 100 Hz.

- A Residual Gas Analyzer (RGA), directly connected to the vacuum chamber, measures the composition of the gas desorbed from the internal surfaces.

- X-rays are measured by a EJ-228 organic scintillator in polyvinyl toluene (PVT), positioned outside the vacuum chamber, at 1 meter far from a glass window. It is connected to a multichannel digitizer, recording energy and time of each single photon detected up to a maximum rate of 350 kHz.

- An Infra-Red Camera is devoted to the monitoring of the temperature inside the vessel. Thermal sensitivity: 0.03°C; each frame is recorded at 50 Hz.
Electrodes

Negative electrode: Sphere AISI304 Ø=40 mm
Positive electrode: Plate AISI304 Ø=108 mm
Gap between the electrodes: 30 mm

Electrodes treatment: dry polishing using abrasive sheets with decreasing grain size
acetone cleaning
ultrasound washing
Tension is regulated by an automatic procedure, symmetrically operating on both power supplies:

\[ K_F = 25 \text{kV/min}, \quad K_S = 0.5 \text{kV/min}, \quad K_{S2} = 0.25 \text{kV/min} \]

\[ V_1 = 0.9V_{BD-1}, \quad V_2 = V_{BD-1} \]

\[ \Delta t = 2 \text{ min} \]
X-rays are emitted by accelerated electrons during high voltage conditioning: we study their energy spectrum in time, single events are distinguished.

**EJ-228 plastic scintillator detector:**
- intended for very fast timing applications;
- in air, 1 m from a glass window DN 100 (5 mm thick);
- connected to a CAEN DT5720B multichannel digitizer;
- Energy and time of each single photon detected is recorded up to 350 kHz.
X-ray energy in this range in organic scintillators is mainly converted to scintillator light via single Compton scattering: the energy distribution is continuous, due to the different scattering angles, till a maximum value, named **Compton edge:**

\[ E_C = \frac{2E^2}{m_e c^2 + E} \]

where \( E \) is the incident photon energy.

Radioactive sources used as known photons emitters:
- \(^{40}\text{K} \rightarrow E = 1461\) keV
- \(^{60}\text{Co} \rightarrow E = 1173\) keV, 1332 keV
- \(^{137}\text{Cs} \rightarrow E = 662\) keV

\[ E (\text{keV}) = E (\text{ch}) \cdot m \]

conversion index
X-ray diagnostics: background and attenuation

Background radiation is subtracted by the measured energy spectrum

X-rays measurement is affected by the possibility to interact with the molecules of the vessel window and of the scintillator plastic:

\[ \Gamma = \Gamma_0 e^{-\mu x} \]

Attenuation coefficient

Glass: \( x_g = 5 \) mm, PVT: \( x_p = 60 \) mm

\[ \Gamma_0 = \frac{\Gamma_m}{\left\{ e^{-\mu_g x_g} \left[ 1 - e^{-\mu_p x_p} \right] \right\}} \]

National Institute of Standards and Technology (NIST)
X-rays energy spectrum

X-ray activity increases with the voltage, but not linearly.

No high energy X-rays after the maximum tension value is achieved.

$V_B = 370$ keV
$t(\text{max } V_B) = 9.5$ h
X-rays energy spectrum

The X-rays spectrum evolves within the tension cycle

\[ S(E) \sim E^{-\alpha} \]
X-rays energy spectrum

\[ \Delta E = 10 \text{ keV} \]

\[ E_1 = 50 \text{ keV} \]
\[ E_2 = 150 \text{ keV} \]
\[ E_3 = 300 \text{ keV} \]
X-rays energy spectrum
The current signals

- $I_+$ and $I_-$ both exhibit the occurrence of spikes or microdischarges (MD): it is an interation between electrodes.

- $I_-$ signal measures an almost continuous current of about 0.01 mA, not symmetrically corresponded by the $I_+$, named in the following inter-MD Current (iMDC). The cathode interacts with the vessel.
The current signals

- MD followed by a non-zero iMDC
- MD followed by another MD
The current signals

For each tension cycle:
- small-current MD followed by iMDC accumulate in correspondence to the initial conditioning phase
- Intensive high current MD are seen at the end of this first initial phase;
- two types of events are almost evenly distributed.
RGA: different gas populations

Negative electrode connected to the vacuum vessel (0 V)
RGA: different gas populations

4 different gas populations:
- Argon (40) injection
- Air puff: O₂ (32), N₂ (28)
- Emission of H₂ (2), CO₂ (44), CO₂(+N₂?) (28) in correspondence to high energy X-rays.
- H₂O (18) slightly increases in time
RGA: different gas populations

[Graphs showing gas populations over time and voltage]
RGA: different gas populations

- Emission of $H_2$ (2), $CO_2$ (44), $CO_2$($+N_2$?) (28) in correspondence to high energy X-rays
- $H_2O$ (18) slightly decreases in time
Summary and conclusions

• HVPTF is an experimental device with the aim to investigate the voltage holding in vacuum in support of MITICA accelerator and as a physical phenomenon.
• Three new diagnostics have been implemented last year, in particular a X-rays detector.
• X-rays spectrum evolves during the tension cycle: high energy events increase during the conditioning.
• A clear relation between I_0 current signal and X-rays measurement: MD are associated to high energy events, iMDC produces half energy X-rays.
• Different conditioning regimes are observed within the tension cycle, in particular during the initial phase.
• The emission of Hydrogen and Carbon dioxide is measured in correspondence of the high energy X-rays detection.
Thank you for the attention
IR camera picture of the stainless steel (cantilever) arm connected to the positive power supply and supporting the planar electrode

Vessel inner wall: two circumferential stains are progressively appeared during the execution of the high voltage tests

The trajectories of positive charged particles, uniformly distributed on the anodic surfaces, have been integrated considering the an axialsimmetric electrostatic field map. The trajectory stops when a charged particle hit an electrode, than the sign of the charge is changed and a new trajectory is integrated. The process has been repeated up to a condition characterized by a stationary mutual-exchange of trajectories. In this geometry, twenty iterations are necessary to converge toward the final configuration.

Δt=8 s;
Interpolation: E=[100,220] keV