Mutual exchange of charged particles in high voltage dc devices insulated by high vacuum*

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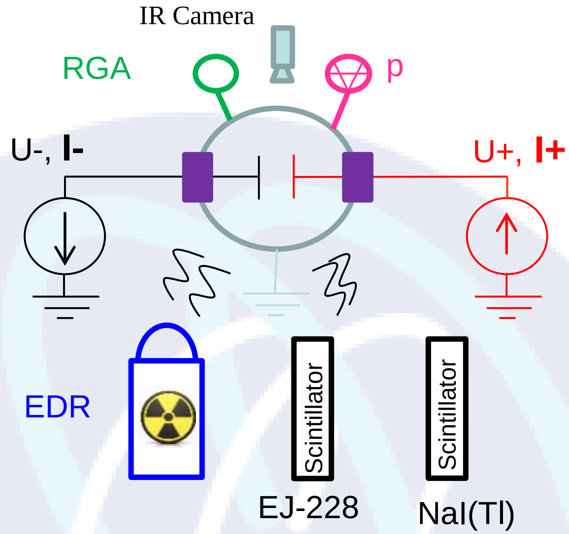
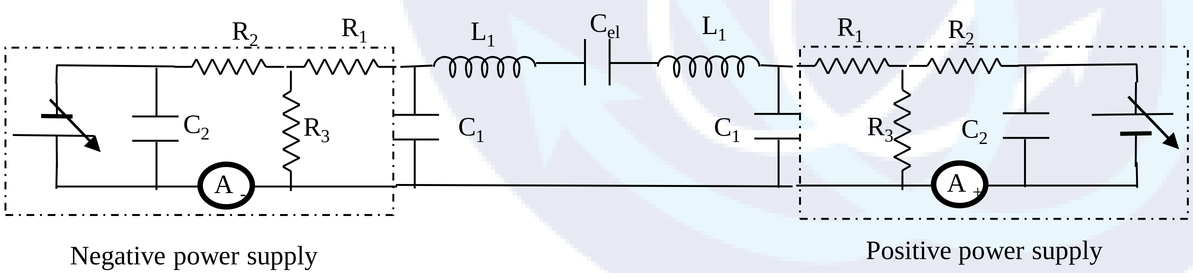
HVPTF description





R_1=R_2=15MOhm
R_3=4GOhm
L=0.3 µH
C_1=0.22nF
C_2=2.7 nF
Cel= 1-10 pF

Maximum electrostatic energy stored @ full voltage ~400J

Stainless Steel vacuum chamber volume 2.4 m^3

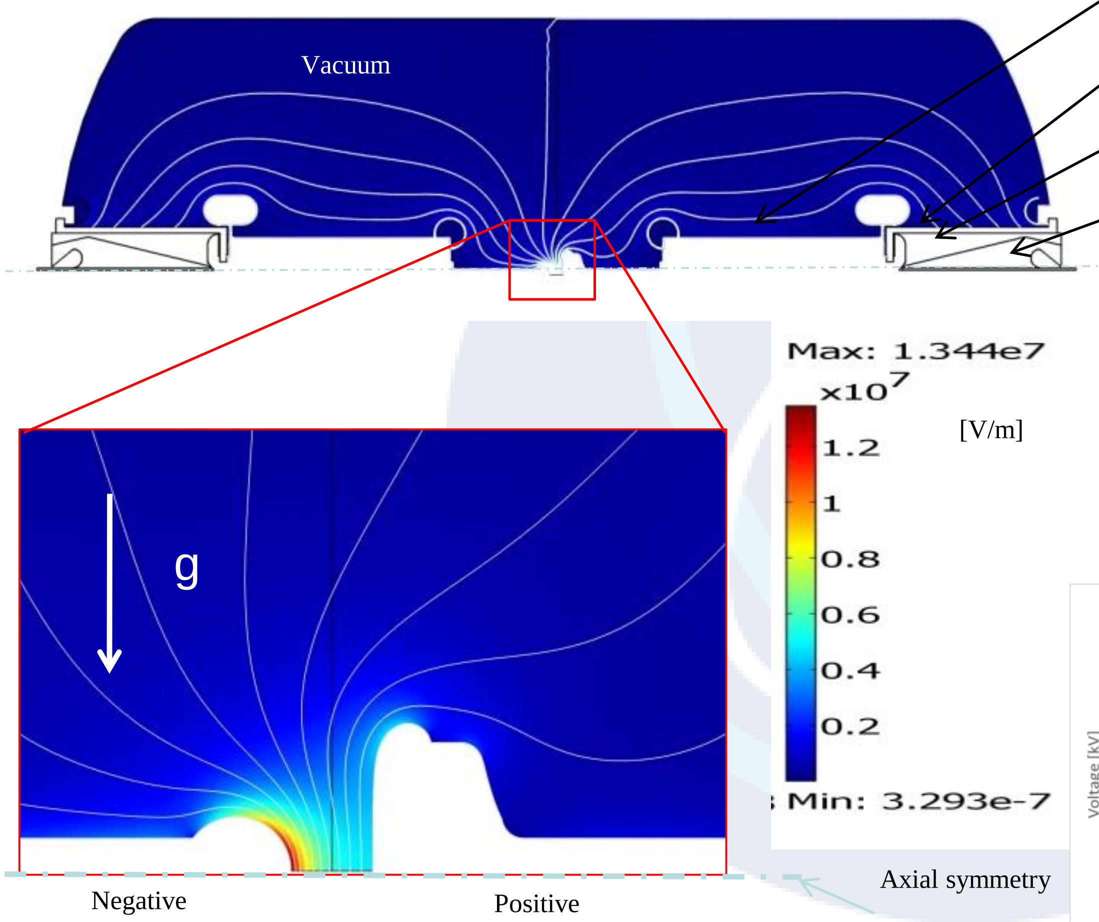
Double polarity configuration
2 Cockcroft-Walton power supplies 400kV$_{DC}$ -1mA (positive and negative unit put in series),
Maximum voltage: 800kV$_{DC}$

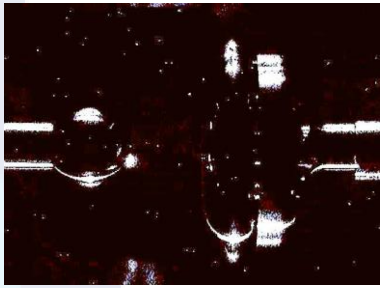
Vacuum & gas injection system
1 turbomolecular pump 1m^3/s baked by a dry scroll pump 0.04 m^3/s,
pressure from 3e-7 to 1e-02 mbar

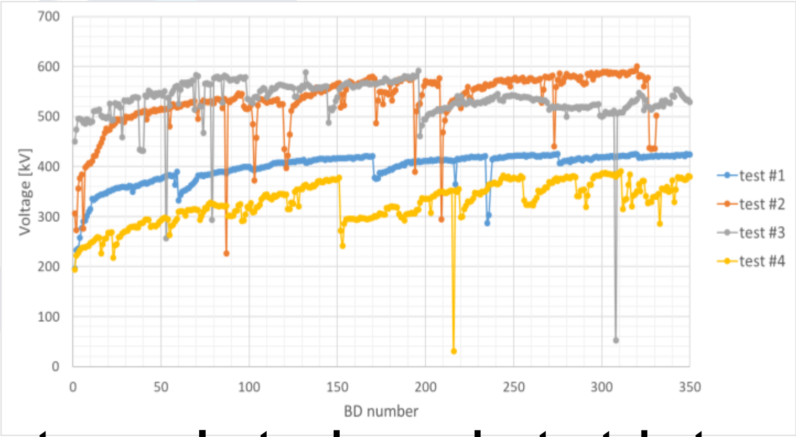
Measured quantities
- ✓ pressure : 1 capacitive, 1 hot cathode and 1 penning pressure gauge [mbar]
- ✓ Equivalent Dose Rate (EDR) [µSv/h]
- ✓ Voltages (U+ , U-) [kV] , Currents **(I+,I-) [mA]**
- ✓ Residual Gas Analyser (RGA) , 1-100 [amu]
- ✓ X-ray spectra two type of scintillators [keV]
- ✓ Ifra-Red Camera [°C]

Ref. [1]

HVTF description







Breakdowns usually occur between electrodes under test but …

Interaction with the vacuum chamber wall

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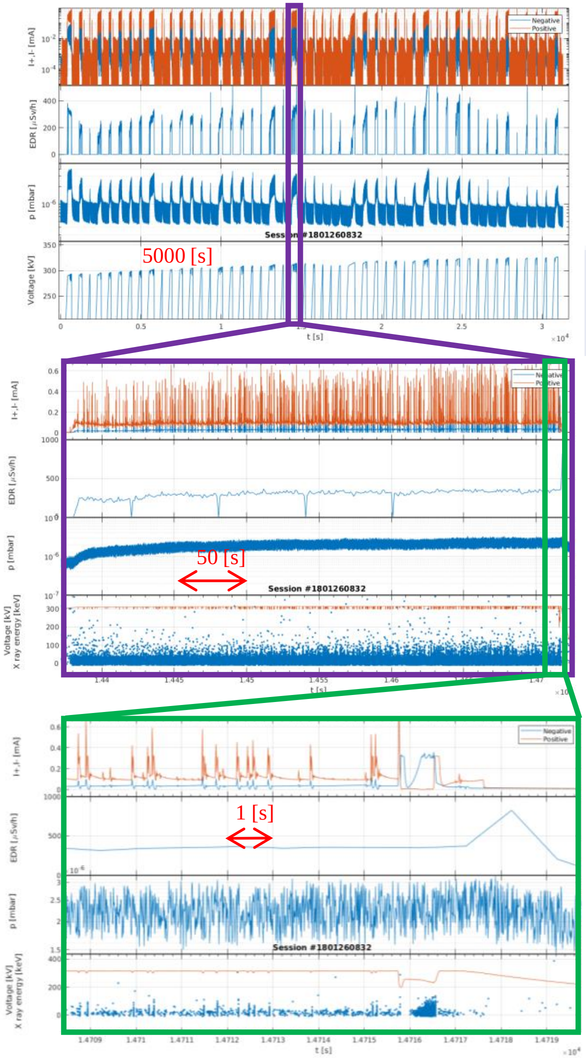
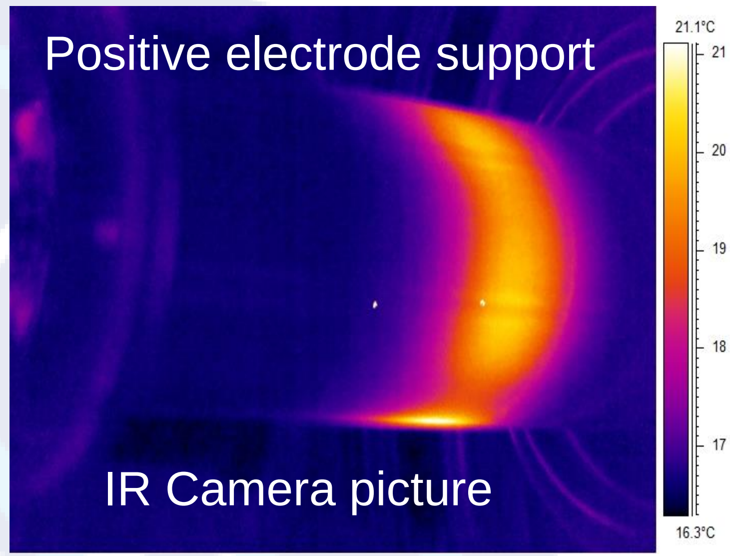
“Spurious “ micro discharge activities occur between single power supply and the grounded vacuum vessel





- ➢I+ > I–, sometimes occurs also the opposite (I- > I+)
- ➢temperature rise only on the metallic cantilever structure connected to the positive power supply has been observed
- ➢No visible glow discharges
- ➢No hot spots on the support of the negative electrode
- ➢No hot spots on the vacuum chamber inner wall

Visual inspection of the surfaces exposed to vacuum

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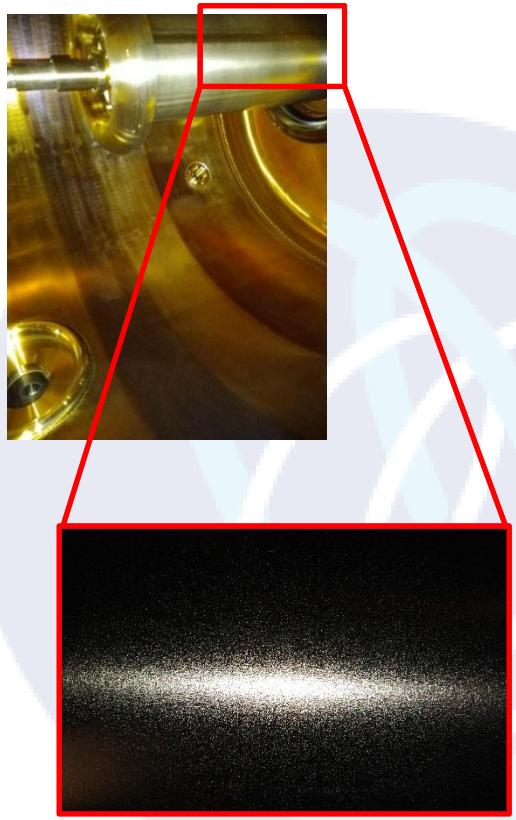
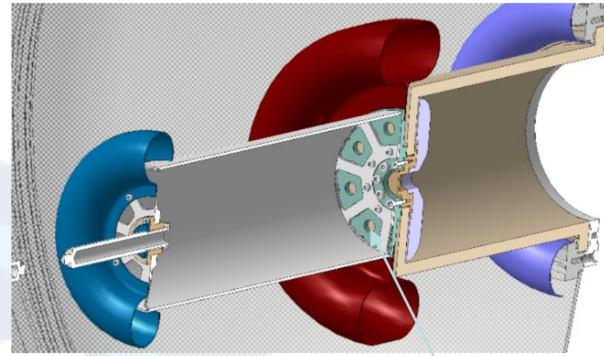
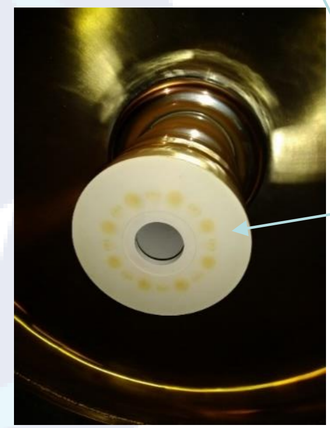
Negative support

2018

Positive support







Regular pattern of spots on ceramic insulator

❖Brown stains have been observed on :

- ❖On the inner wall of the vacuum chamber
- ❖ On ceramic insulator (positive feed through) in a region with no electric field

❖Annular regions without stains are in front of each support

❖Traces of metallic fusions can be observed by naked eye on the cylindrical support sustaining each electrode

Energy Dispersive X-ray Analysis (EDX)

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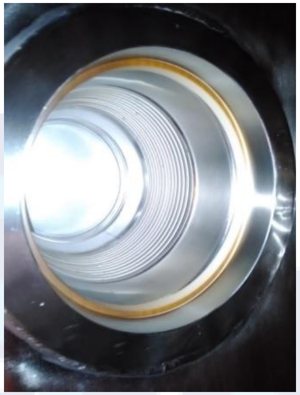
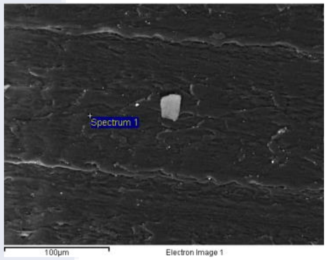
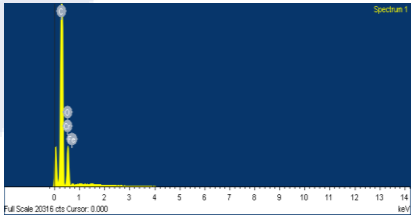
The brown layer was deposited also an a peek insulator







The brown layer composition is compatible with Iron and Chromium, the layer appears very thin (t_k< 1mm). Fe and Cr are consistent with the composition of the stainless steel which is the sole metal adopted for the vacuum chamber and for the electrode under test➔ expansion of metal vapors

Evidences in other applications

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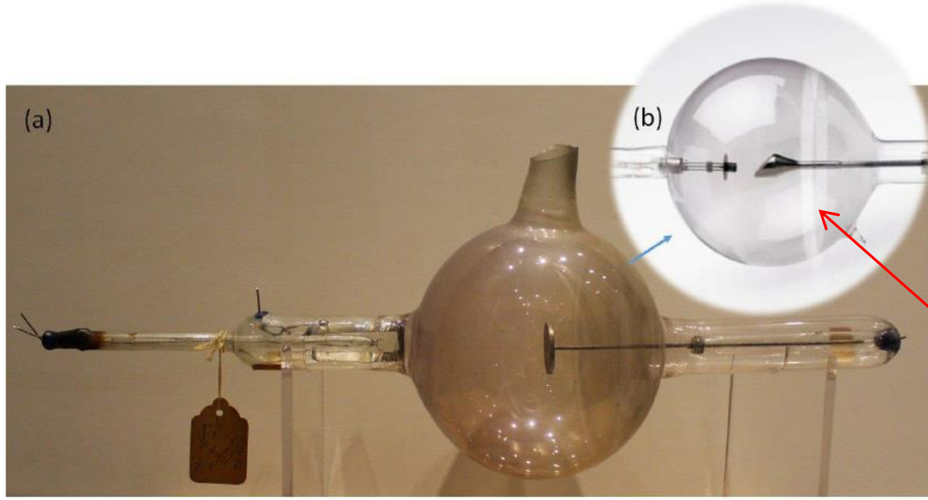
MEDICAL PHYSICS INTERNATIONAL Journal, Special Issue, History of Medical Physics 1, 2018



Annular region without stains

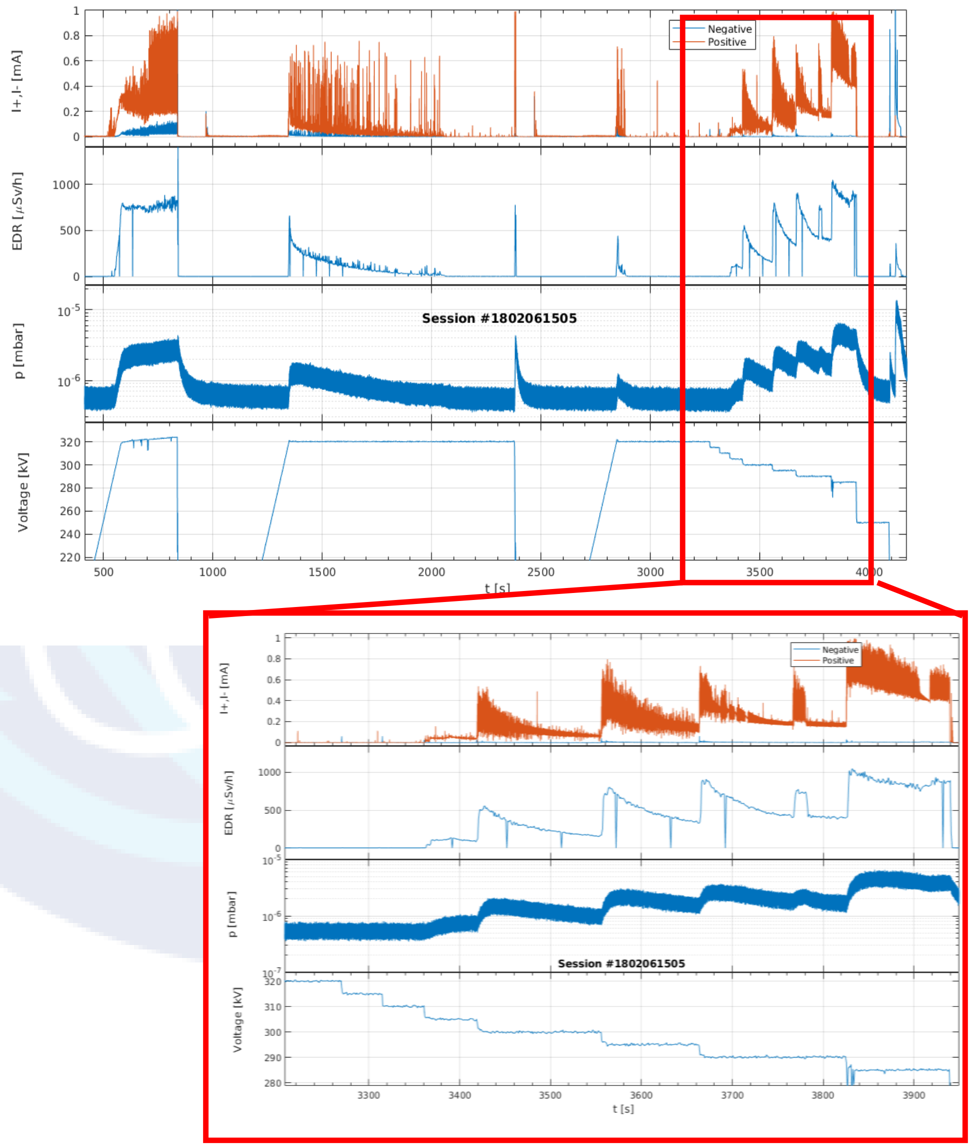
Figure 10 Photo, taken on April 30th, 1913, of one of the original experimental X-ray tubes used by W.D. Coolidge at the GE Research laboratory (Schenectady, NY, USA). It incorporated a tungsten thermionic emitter inside a highly evacuated sealed glass envelope. This concept allowed for very stable operation and repeatable results during imaging. For the first time, X-ray production was easily controllable by setting tube current independently from penetrating power and image contrast, which are a function ofthe tube voltage across the anode-cathode gap. Another "first" for this tube was the use of tungsten as a target material. (b) Close-up photoof a series production unit delivered from 1914. (Pictures courtesy of GE.)

"After X-ray irradiation (curve c) the glass shows strong solarization effects with broad bands in the UV near 200 nm and in the visible range near 450 nm which cause a yellow to brown color. The color centers produced had a great stability at room temperature. *" D.Ehrt and W. Vogel "Radiation effect in glasses" Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*
Volume 65, Issues 1–4, 1 March 1992, Pages 1-8

Perturbation of equipotential surfaces

Test sequence:

1) system conditioned by automatic conditioning procedure
2) Voltages kept constant at 320 kV (-160kV, +160kV)
3) wait sufficient time in order to quench any microdischarge activity
4) at t >3270 s, only the voltage of the negative power supply was manually decreased step by step
5) at -150kV ; 160kV the microdiscarges restarted at the <u>positive</u> side (I+ > 0.1 mA) although |V-| was decreasing



Numerical analyses and discussion

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The microdischarge activity has involved mainly the vacuum vessel and the positive power supply rather than the two electrodes

The peculiar spatial distribution of the emission sites on the electrode surfaces, has been analyzed thanks to the idea proposed in [*****] where <u>a mutual exchange of charged particles, with opposite sign, is simulated between electrodes having a generic shape</u>

$$A \cdot B + C \cdot D \geq 1$$

$$B := \frac{\Gamma_{electrons}}{\Gamma_{+ions}} \qquad D := \frac{\Gamma_{electrons}}{\Gamma_{photons}} \qquad A := \frac{\Gamma_{+ions}}{\Gamma_{electrons}} \quad C := \frac{\Gamma_{photons}}{\Gamma_{electrons}}$$

A steady interchange of charged particles and photons between cathode and anode is one of the hypothesis proposed in the past literature [**] to explain breakdown events over long vacuum gaps.

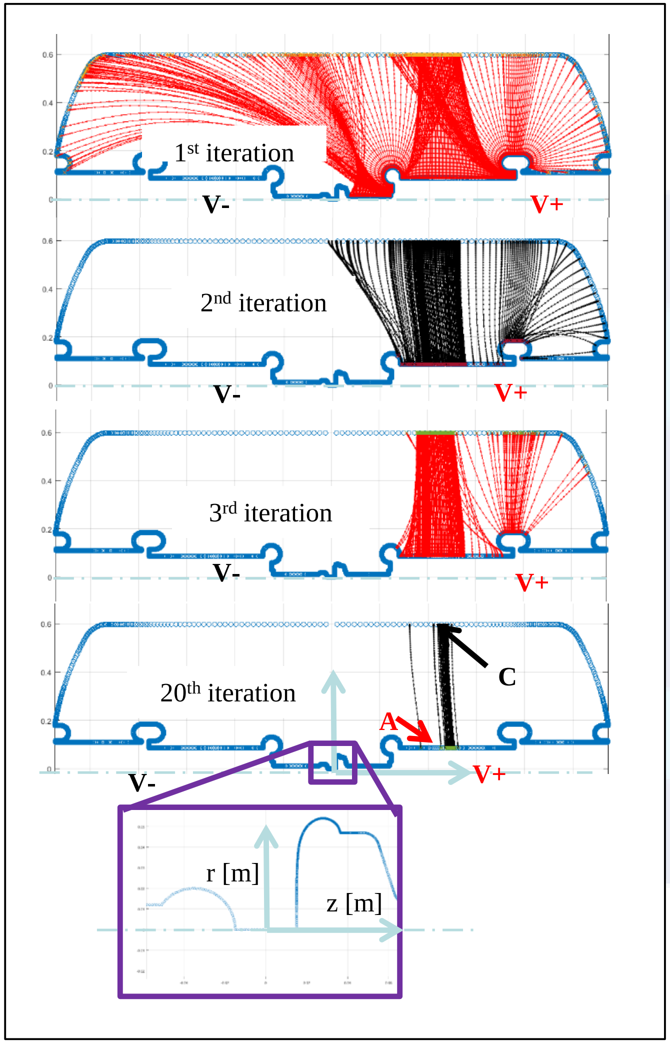
Direct measurements of coefficients A and B carried out by the same authors , and others [***] would not immediately support the validity of such equation

•**M. Cavenago, P. Antonini, P. Veltri, N. Pilan, V. Antoni, G. Serianni "Cascades of Secondary Particles in High Voltage Accelerators", in "Comsol conference , Boston (2009).**

****** Trump J G and Van De Graaff R J 1946 *J. Appl. Phys* 18 327

*** Filosofo I and Rostagni A 1949 *Phys. Rev.* 75, 1269

Mutual exchange of charged particles : the Discharge attractors



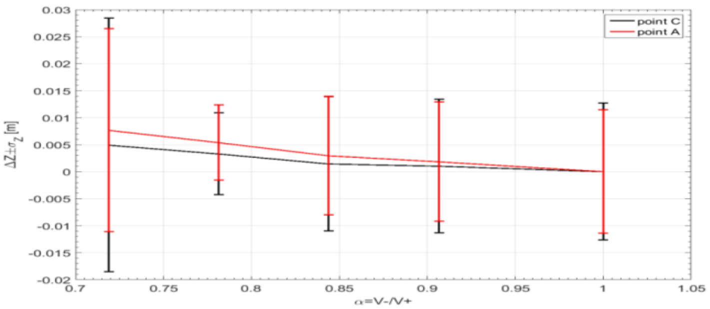
Red trajectories ➔ positive charge particles

Black trajectories ➔ negative charge particles

The trajectories have been grouped and exchanged only between two points A and C, respectively on the anode support and the cathodic surface of the vacuum vessel. Such points are called discharge attractors as referred in [*]

It is possible to demonstrate that the trajectory path of a charged particle in an electrostatic (irrotational) field, assuming classic motion and zero initial velocity, depends only on the shape of the domain and the ratio of the applied voltages (in case of multi-electrode system)

Under such conditions the attractor locations depend only on the shape of the electrodes and on the ratio between the applied voltages



•M. Cavenago, P. Antonini, P. Veltri, N. Pilan, V. Antoni, G. Serianni "Cascades of Secondary Particles in High Voltage Accelerators", in "Comsol conference , Boston (2009).

Conclusions

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- Experimental evidences concerning the existence of accumulation points during occurrence of micro-discharges have been observed during the high voltage conditioning of an electrostatic device insulated by large vacuum gaps.
- A mutual exchange of positive-negative charged particle is the mechanism which presumably causes this phenomenon and defines the position of the micro-discharge attractors.
- The attractors regions due to the regenerative processes of charged particles between cathode and anode have been identified thanks to numerical ray-tracing simulations.
- The position of the attractors depends only on electrode shape and the ratios of applied voltages.
- A perturbation of the trajectories position by altering the voltage distribution has been sufficient to initiate the micro discharge occurrence.
- The existence of phenomena able to concentrate the dissipation of power in specific location on the electrode surfaces during the high voltage conditioning in vacuum could be exploited in the development of neutrons sources applications.

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