# THE ENERGY SPECTRUM OF THE "RUNAWAY" ELECTRONS FROM A HIGH VOLTAGE PULSED DISCHARGE

C.Ruset
Institute for Physics and Technology of Radiation Devices
P.O.Box M.G.-6, Bucharest, Romania

If a strong enough electric field is applied to a plasma, the electrons gaining an energy higher than the thermal energy, between two collision, can enter a state of continuous acceleration. Their mean free path increases rapidly with energy rise. These electrons are known in the literature as "runaway" electrons /1/.

The aim of this paper is to present some experimental results on the influence of the pressure, upon the energy spectrum of the "runaway" electrons, generated into a pulsed high voltage argon discharge at 160 kV for approximately 0.8 $\mu$s. Discharge current varies with pressure from 10 to 300 Amps.

## Experimental Arrangement

The electron gun (EG) (presented in /2/) consists of a glass tube (T) (5 cm in diameter and 100 cm long) ended by a cathode (C) (1 mm diameter tungsten wire with one end sharpened at $5^{o}$) and an anode (A) (stainless steel grid 70% transparency).

The "runaway" electrons energy spectrum was determined by means of a magnetic analyzer (MA) with a $90^{o}$ deflection. The deflected electrons were detected with a scintillator (S) - photomultiplier (FM) system resulting a high sensibility and a very good signal to noise ratio.

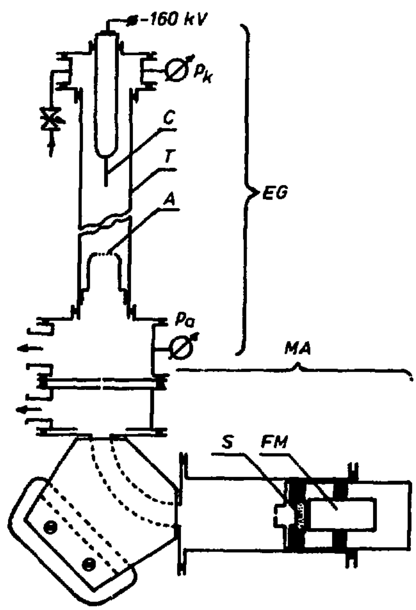


Fig.1

By introducing the value of the magnetic induction B in the following equation, the kinetic energy of the captured electrons, E, can be determined.

$$E = m_o c^2 \left[ \left( 1 + \frac{e^2 B^2 r_o^2}{m_o^2 c^2} \right)^{1/2} - 1 \right] \qquad (1)$$

where $r_o$ is the equilibrum radius of the electrons, $m_o$ and e are the rest mass and the electron charge respectively. By varying the analyzer magnetic field, the photomultiplier oscillograms $U_p(t)$, for corresponding energies given by Eq.(1), were recorded. By working out the time integrals of these signals, the energy distribution of the electrons f(E), was found.

$$f(E)=\frac{const.}{(E-E_a-7.26)\cdot E}\cdot\int_{(T)}U_p(E,t)dt \qquad (2)$$

where $E_a$ = energy calculated to be lost in the 2000 Å aluminium film deposited on the scintillator surface. The apparatus and the method of determining the energy spectrum was described elsewhere /3/.

## Experimental Results and Discussions

The discharge was produced in flowing argon for a steady pressure gradient of about one order of magnitude between C (higher pressure) and A (lower pressure ≈ $p_a$). The "runaway" electrons energy spectra for tree pressure regimes ($p_a$=$10^{-5}$; $6\cdot10^{-5}$ and $2\cdot10^{-4}$torr) are presented in Fig.2.

It can be noticed that the beam has a wide energy distribution. Electrons having energies higher than the energy corresponding to the maximum discharge voltage were detected. The presence of such "ultra-fast" electrons was also reported by other authors /4,5/. In our case, along with the pressure rise, which means a higher plasma concentration and beam current intensity, a significant diffusion of the electrons in the velocity space occurs. This leads to a modified energy spectrum, presenting a relative rise in the number of electrons having low and very high energies and a relative reduction in the number of medium energy electrons (Table I). ΔN/N represents the ratio between the number of electrons within a given energy range and the number of electrons having E ≥ 12 keV. The table I also presents the maximum energy of "runaway" electrons for every pressure regime.

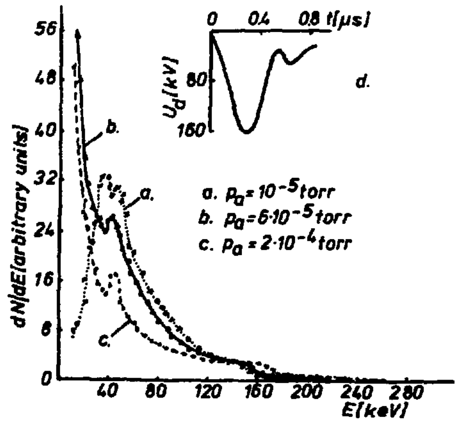


Fig.2

Although the beam current rises with pressure, the number of electrons with energies higher than 12 keV decreases. Thus, for a variation of $p_a$ from $6\cdot10^{-5}$torr to $2\cdot10^{-4}$torr the number of fast electrons (E ≥ 12 keV) is reduced by 28%. Consequently, it results an important rise in the number of low energy electrons (E < 12 keV).

This phenomenon can be explained by the electrons spreading on plasma oscillations. It is known that by passing an electron beam through a

Table I

| $P_a$ (torr) | ΔN/N % | | | $E_{max}$ (keV) |
|---|---|---|---|---|
| | 12≤E≤20 keV | 40≤E≤100 keV | E≥140 keV | |
| $1\cdot10^{-5}$ | 3.8 | 55,4 | 2.8 | 209 |
| $6\cdot10^{-5}$ | 17.7 | 44.8 | 3.5 | 219 |
| $2\cdot10^{-4}$ | 20.0 | 34.8 | 7.7 | 272 |

plasma, wide range frequency instabilities are excited, depending upon plasma and beam parameters. The beam electrons appear at different phases of the excited waves, and are unevenly slowed down, function of the phase and distance covered in this regim. A small number of these electrons, captured by accelerating phases, reach energies higher than the energy corresponding to the voltage applied to the discharge tube. Simultaneous with the pressure rise, meaning a higher discharge current, a rise of the oscillations energy occurs, thus enhancing the plasma - beam interaction and widering the energy distribution.

The spectrum maximum obtained at about 45 keV is due to the electrons generated during the final phase of the high voltage impuls, that is, between 0.6 and 0.8 μs. (Fig.2 d)

References

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