Dark Current under Low and High Electric Field.

G.Bienvenu P.Brunet
LABORATOIRE de L'ACCELERATEUR LINEAIRE D'ORSAY.
LAL Bat 201 service SERA
91405 ORSAY FRANCE

Abstract

Using CERN/LIL type cells an one meter long high temperature brazed, S band travelling wave section has been tested in our high power test facility NEPAL. In order to provide data for S band linear collider (SBLC), we have systematically investigated the characteristics of the dark current from this structure under low electric field conditions (less than 20 MV/m). We show that spectrum peaks are close to the nominal energy of the section so that dark current may be transmitted from section to section. An overview of experimental set-up and method of measurement of very low self-emitted current is described, the spectrum chape is discussed.
A beam has also been accelerated under high electric field conditions, the structure being fed through a peak power multiplier (SLED type).

1 INTRODUCTION TO LOW ELECTRIC FIELD CONDITIONS

In accelerating structures running under low electric field - lower than 20 MV/m - dark current is generally disregarded. If a long multi-section linac is proposed (SBLC) the dark current will be transmitted from section to section. At the end of the machine, the value of self emitted current may grow-up enough to disturb the main beam. In order to characterize the flow of field emitted electrons the measurement of an extremely low current is required. This problem is cleared-up by an electron counting system usually dedicated in particle physics domain.

2 ORIGIN OF DARK CURRENT UNDER LOW FIELD

Electrons pulled out from cavity surface, give a beam, for all phase conditions, if the strength of accelerating field reaches the critical value E_c:

$$k\pi < \frac{eE_c\lambda_g}{m_0c^2}$$

where k is a factor dependant of the intern shape of cells. usually $k \simeq 2$[1] so that for an S band structure:

$$E_c > 30MVm^{-1}$$

If the field is lower than E_c, dark current is not directly yielded by field emitted electrons, but by secondary electrons, like it is reported on simulation [2] of figure 1.

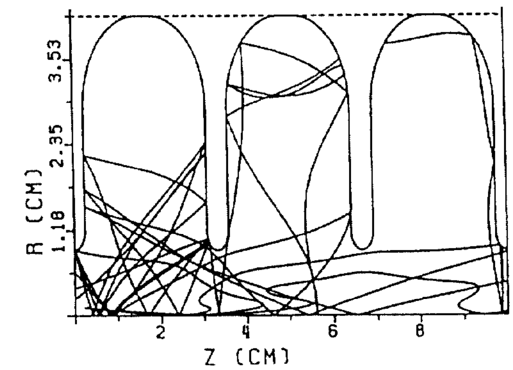

Figure 1: Simulation of dark current under low field

3 EXPERIMENTAL SECTION

The experimental section SERA/LIL-2 is an one meter long S band TW element. It is derived of our work on LIL structures [3]. Contrary to LIL technic cells are assembled by high temperature brazing. Mains characteristics of section are given by the table 1.

Table 1: experimental section parameters

Nominal frequency	2998.55 MHz
Total length	1.10 m
Number of cells	30
Shunt impedance	70 $M\Omega m^{-1}$
Attenuation	3.0 dB
Filling time	0.55 μs
Energy gain	$6.2\sqrt{P_{MW}}$ MeV

4 MEASUREMENT CONDITIONS

The sketch of experimental set-up is reported on the figure 2. The section is fed by a 3 μs RF pulse with a 100 Hz. repetition rate.
The collimator input aperture is fixed at : $5X5$ mm^2 and the image slit of spectrometer is opened at 0.4 mm

5 COUNT DEVICE

Three plastic scintillators S_1 S_2 S_3 are set on the deviated way of spectrometer axis, as is reported on the figure 3.

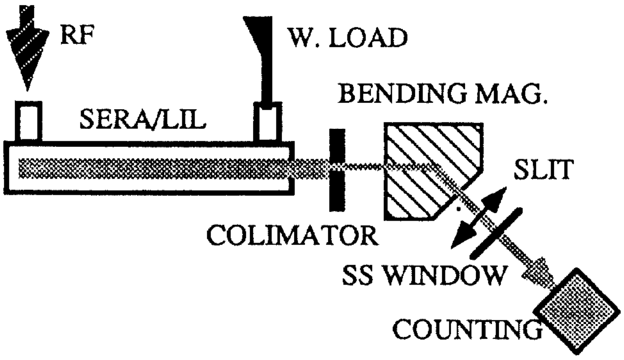

Figure 2: Measurement set-up

Gains of photomultipliers are equal, their signals are sent to three discriminators which give 5 ns pulses . A RF synchronous signal is injected into the gate G.
An event is considered as good if:

$$\frac{(S_1 \bigcap S_2) \bigcap S_3}{(S_1 \bigcap S_2)} > 0.6$$

For an adequate statistics, the counting time has been fixed at 100 s.

6 RESULTS

Spectrums of figure 4 has been respectively recorded at the beginning of experiment and after 3 h of continuous running. The average accelerating field is 16.4 MVm^{-1} and the theoretical maximum gain is $U_{Max} = 18\ MeV$ After 3 h the dark current amplitude decreases by about 10%. After a break, the initial intensity level is found again. On the figure 5 is reported the time dependence of the self emitted current, this bargraph is the sum of spectrums, recorded at various moments into the RF pulse (with a path of 0.5 μs).

6.1 Charge and intensity

Under our conditions, the electric charge and the peak current are respectively:

$$Q = 0.2\ fC$$

$$I = 60\ pA$$

7 SPECTRUM SHAPE

In a constant impedance structure, the surface field decreases all along of the section, so that the number of emitted electrons (respectively the number of secondary electrons) decreases versus the RF Fowller-Nordheim law. As electrons are rapidly relativistic their energy gain is directly dependent of their emitted point.The spectrum peak is maximum for the maximum energy gain (18 MeV) and decreases exponentially in accordance with experimental records.

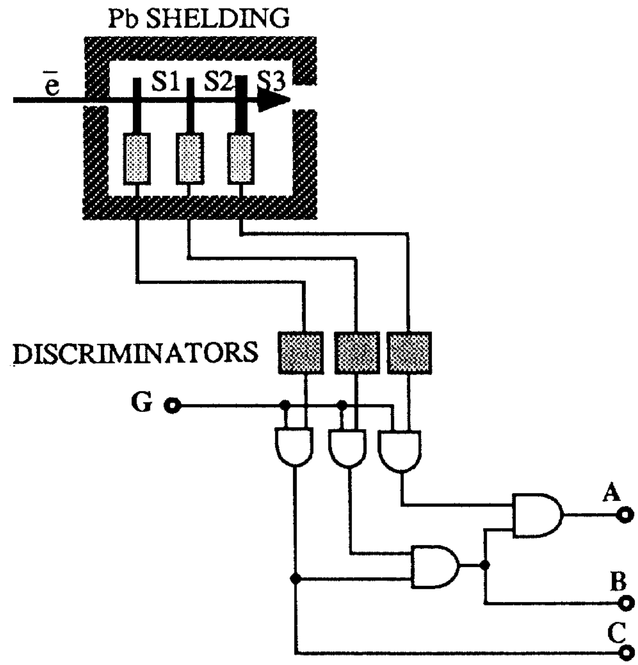

Figure 3: Counting device

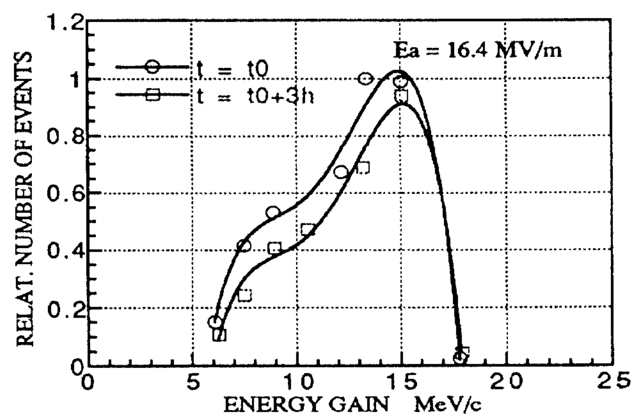

Figure 4: Spectrums of dark current

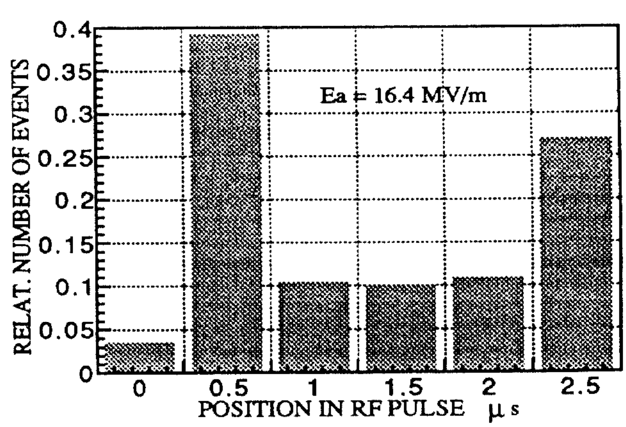

Figure 5: Time dependance of dark current

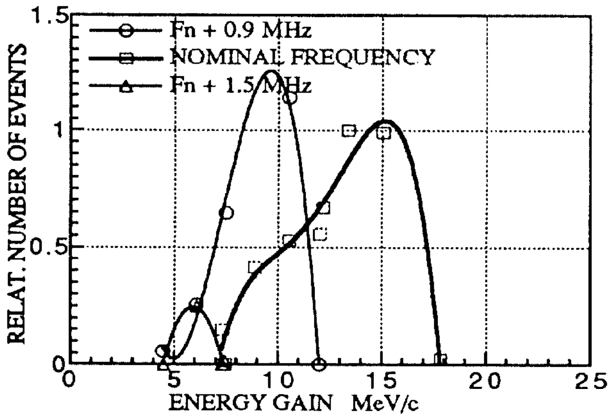

Figure 6: Relative number of events versus frequency

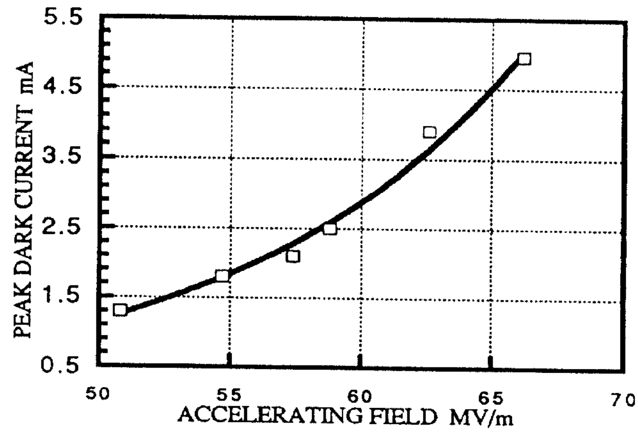

Figure 7: Dark current intensity in compressed mode

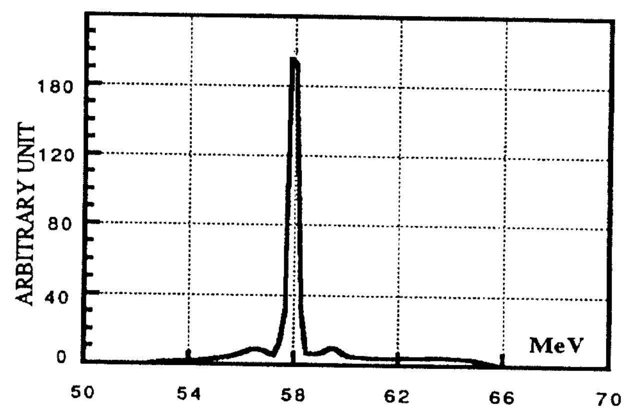

Figure 8: Accelerated current spectrum

8 FREQUENCY DEPENDANCE

The consequence of a increase in the RF frequency has been also investigated in a narrow band around the nominal frequency ($F_n = 2998.55\ MHz$). Results are reported on the figure 6. The maximum intensity of dark current is obtained for $F = F_n + 0.9\ MHz$ (gain of 30%), consecutively the maximum energy decreases as far as 12 MeV.

9 HIGH ELECTRIC FIELD CONDITIONS

The main RF source of NEPAL supplies a 35 MW rectangular pulse of 4.5 μs length. It is also possible to feed the structure by a compressed pulse (SLED). In this case the buncher is connected to an auxiliary RF source of 4 MW. In compressed mode the available peak power is about of 210 MW

9.1 *Rectangular pulses*

With rectangular pulses, it is possible to feed our section at the nominal work conditions of the main klystron. For 35 MW the accelerating field reach 40 MVm^{-1}. Unfortunately the level of the dark current is too high to be measured by the device described in 5 and too low for a direct measurement by a faraday-cup located at the direct output port of spectrometer.

9.2 *Compressed pulses*

In compressed mode the intensity of dark current is enough high for a measurement by means of torroïd transformer set at the end of deviated way.
The peak dark current intensity versus the average accelerating field is reported on the figure 7, for a 0.8 μs compressed pulse.

10 ACCELERATED ELECTRON BEAM

Two moving plungers, located into the SLED cavities, allow us to switch easily from a SLED RF type pulse to a rectangular pulse. In this two cases, for radiation safety reasons, the repetition rate is decreased at 25 Hz.
The compressed pulse mode has bean used for accelerating routinely an electron beam of 600 mA as far as 58 MeV. The energy spectrum is reported on the figure 8. After subtracting the thermïonic gun and buncher gain the energy gain for our SERA/LIL-2 section is:

54 MeV per meter

11 REFERENCES

[1] G.Bienvenu, Mesure et étude de l'auto-émission électronique et du champ électrique des sections accélératrices d'électrons,LAL/RT 93-17 Nov 93

[2] P.Fernandes, Proceeding of Linear Accelerator Conference, 1988 Stanford p. 330

[3] R.Belbéoch et coll, Rapport d'étude sur le projet des linacs injecteurs de LEP (LIL), LAL/RT 82-01 Jan 82