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HIGH POWER CONDITIONING OF THE 202 MHZ I-H TANK 2 AT LINAC3

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1. INTRODUCTION

Recent ion linac projects need to accelerate efficiently high currents of low charge ions in a limited length, requiring high gradients in the accelerating structures. In order to explore the maximum field achievable in an Interdigital-H type structure, an experiment has been organised at the CERN Linac3 in collaboration between RF Group, HP Group and GSI, Darmstadt.

At the end of the 1997 Linac3 run, the RF amplifier layout has been rearranged in order to allow feeding the IH Tank number 2 (1.55 m long, 28 gaps, frequency of 202.56 MHz) with up to about 2 MW pulsed RF power. The aim of the experiment was to reach the highest possible field level, at pulse length variable between 200 μs and 1 ms. The time interval between pulses was 1.2 s, the standard Linac3 value.

2. SET-UP

For the normal Pb27+ operation of Linac3, Tank2 requires 320 kW power. The RF amplifier allows for a maximum output power of 800 kW, and during a test in 1996 the cavity was easily conditioned up to this power level [1].

In order to provide a higher power, a special amplifier arrangement has been prepared, following a suggestion by W. Pirkl. The tube used in the final amplifier stage (Thomson TH170R) can deliver a power in excess of 2.5 MW, however at a duty cycle lower than 0.3%, provided that enough drive power and anode voltage are available. This higher drive power was obtained by inserting in the Tank 2 amplifier chain the final amplifier of Tank 3, the two RF chains of Tank 2 and 3 being identical, acting as a driver for the final amplifier. The new amplifier layout, shown in Figure 1, required some work on the RF piping at high power (rigid lines) plus some tedious re-arrangement of the interlock cabling, and was able to deliver a power of about 2 MW. For the maximum pulse length of 1 ms and the repetition rate of 0.8 Hz, the resulting duty cycle of 0.08% was well inside the limits for the RF tubes.

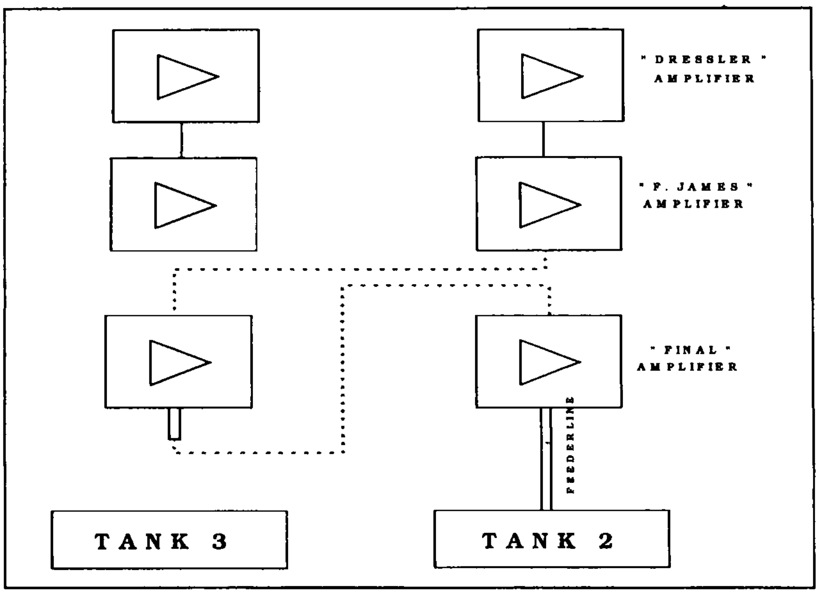

Figure 1 : Amplifier Set-up for the tests. The dotted line shows the temporary connection installed for the tests.

3. CONDITIONING HISTORY

A 14 day time slot was made available for the high power tests, between the end of the 1997 Linac3 run (November 17th) and the beginning of the CERN winter shut-down, when the services (water, etc.) had to be stopped for maintenance. The cabling of the new amplifier layout took about one day, and then the conditioning started.

The conditioning process had to be interrupted several times. A first stop was due to improving the overall safety of the installation, in order to obtain the clearance from the PS Division Safety Officer (high X-ray levels were reached during the tests). Then, the cathode switch circuit of the final amplifier had to be repaired twice, before the right timing between input RF and cathode switching time was found. Finally one full day stop was required to allow access to the Linac3 area for fire detection tests. Therefore, the net time available for conditioning amounted to 230 hours (i.e., slightly less than 10 days).

First of all, the power was gently pushed up with a pulse length of 200 μs. Breakdowns with associated strong degassing started from about 700 kW. The vacuum system pumping rate finally determined the amount of breakdowns being tolerable and therefore the speed of the conditioning process. Under normal conditions, the vacuum in Tank2 is the best in all the Linac3 complex, 4E-9 mbar. During the conditioning, we noticed that the cavity was not able to recover from a series of breakdowns when the pressure went in the E-6 range, thus we tried always to adjust the power in order to stay in the E-8 and E-7. This adjustment could easily be done manually, and we did not need to use computer programs for controlling the conditioning process. Instead, the computer was used to register the vacuum level at regular intervals, to log the breakdowns, and to calculate automatically cavity voltage, power levels and tube gains.

Figure 2 shows a plot, drawn from one of the computer logs, of integrated number of breakdowns (= pulses where the cavity could not reach the programmed voltage) and corresponding pressure during one night (12 hours at 780 kW) of the pre-conditioning phase.

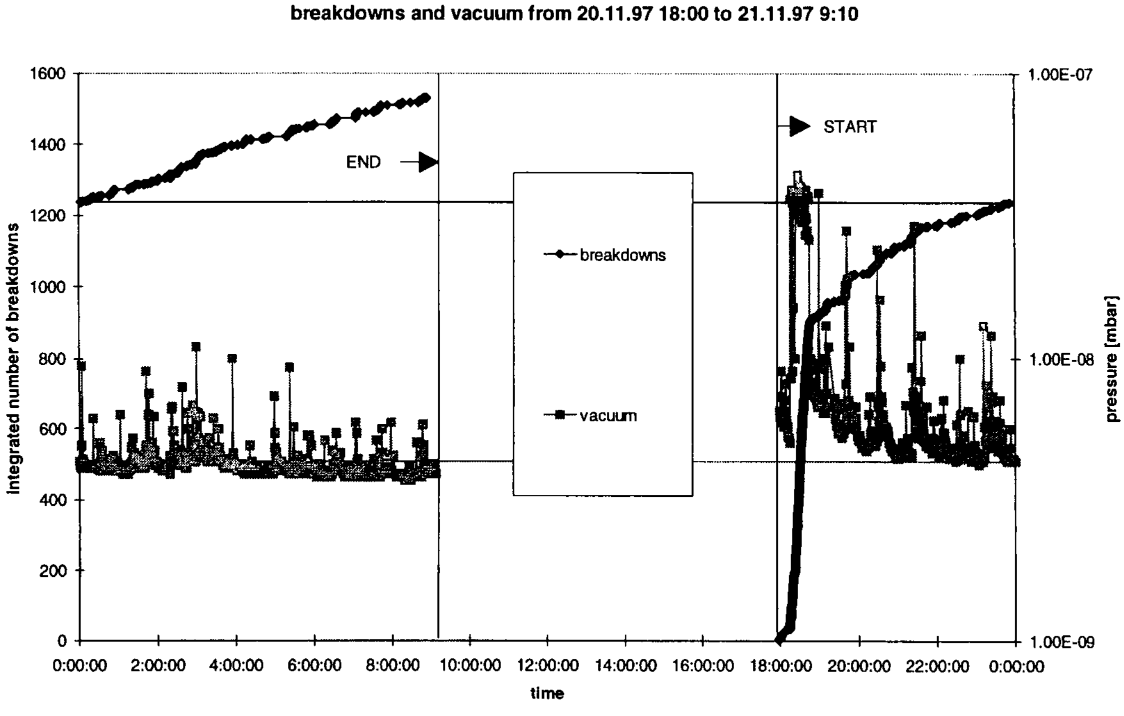

Figure 2: integrated number of breakdowns and pressure during the night 20/21.11 (input power 780 kW). At midnight, the curves re-start at the beginning of the graph.

After four days of pre-conditioning up to about 800 kW, the degassing from the surfaces decreased drastically, and the power could be pushed up more rapidly. Finally, we reached a power level of 1.21 MW, with a stable operation (few breakdowns), however impaired by high amounts of dark current (see later). At this point, instead of trying pushing higher the field, the pulse length was increased to 500 µs and after 48 hours reconditioning from 1 MW, the maximum stable level at the higher pulse length, we reached a power of 1.3 MW. Beyond this power level, heavy sparking started with high degassing. The next step was to further increase the pulse length to 1 ms, and restart conditioning from 800 kW up to a maximum of 1.2 MW obtained after 3 days. Rising the field beyond this level led again to heavy sparking, with an almost immediate degradation of the vacuum.

Figure 3 resumes the conditioning history (power to the tank as function of hours from the start of the tests), while Table 1 reports the maximum voltage achieved, in units of the nominal voltage for Pb27+, and the corresponding peak surface field reached on the drift tubes, in MV/m and in units of the Kilpatrick field at 202 MHz (14.8 MV/m). The field distribution on the drift tube surface will be discussed in the next Section.

The voltage was measured at a probe on the cavity, and compared to the nominal voltage measured during operation.

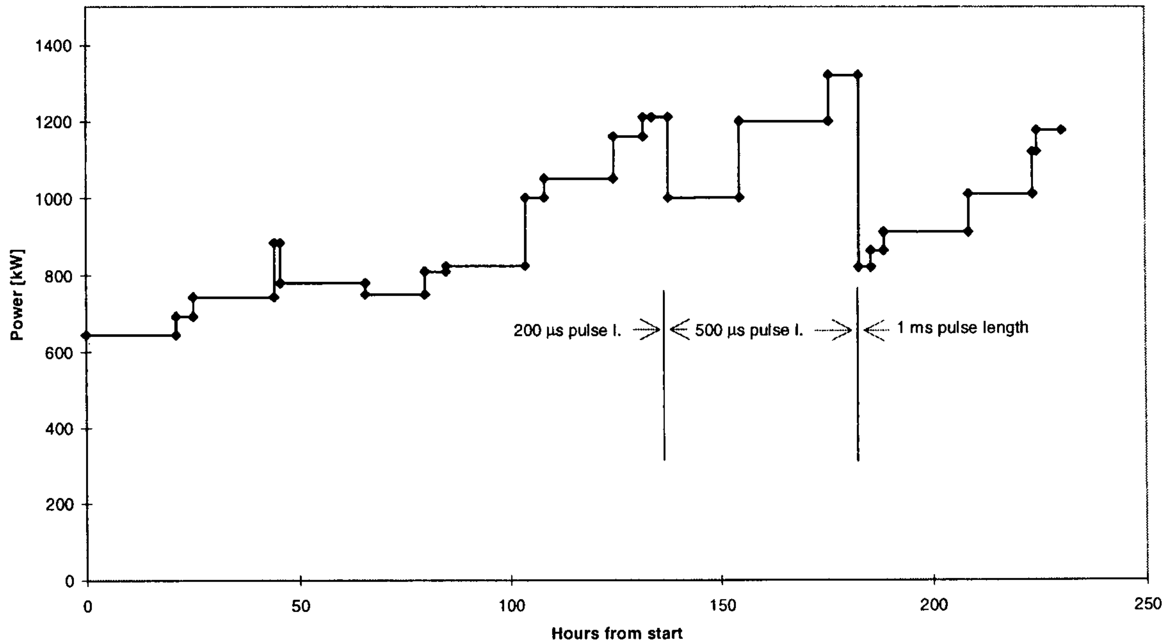

Figure 3 : Conditioning History

Pulse length	Voltage	E-field on	drift tube	Max. local E- field on tube		Effective tank acc. field
[µs]	units of Pb27+ voltage	[MV/m]	units of Kilpatrick	[MV/m]	units of Kilpatrick	[MV/m]
200	1.71	51	3.5	70	4.8	10.1
500	1.82	54	3.7	75	5.1	10.7
1000	1.67	49	3.3	69	4.7	9.8

Table 1 : maximum voltage and peak surface field reached during the tests

4. SURFACE FIELD DISTRIBUTION

In order to know the value of the surface field reached in the cavity during the tests, the electric field distribution around the gap number 9, where the maximum surface fields occurs, has been calculated with the program MAFIA. The result is shown in Figure 4. In the Figure are also reported the calculated values of the electric field at four points on the drift tube surface, corresponding to the maximum voltage reached.

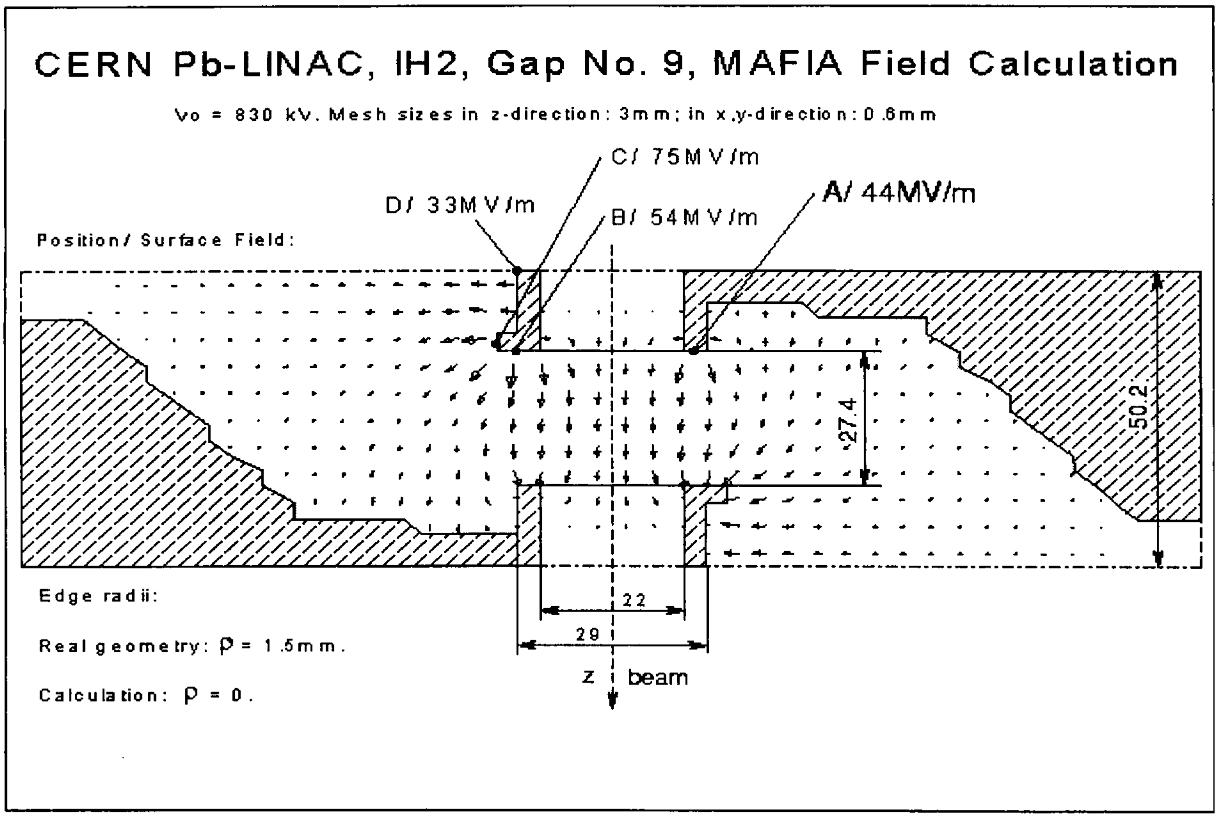

Figure 4 : MAFIA calculation of field distribution in gap number 9, for the maximum voltage reached during the tests.

In the MAFIA simulation the drift tube edges are not rounded, in contrast to the real geometry, and this leads to an underestimation of the field at point A. Instead, the other field values should be closer to reality, being calculated far enough from the square edges. We can consider the field in point B as being representative for the field on the drift tube edge, while point C represents the maximum field reached only in a very localised spot.

In conclusion, during the test surfaces fields well above 3 Kilpatrick were reached, while on small localised spots the field was as high as 5 Kilpatrick.

5. RADIATION AND SAFETY

The high level of X-rays produced during the test forced to take some additional precaution. All the cavity controls were possible from a position some 10 m away from the tank. The doors to the Linac3 hall were locked, and an interlock was added that reduced the RF level at a radiation-safe value in case somebody would open the door.

Radiation levels were measured in two positions, on an Argon chamber placed at about 4 meters from the tank and on a PMXC chamber placed closer to the tank, at about 80 cm from its axis. Occasionally, some measurements were done directly at contact with the tank. Figure 5 shows the dose rate on the PMXC chamber as function of RF power to the cavity, for 500 µs pulse length and 0.83 Hz repetition rate. The dose rates measured at 1.35 MW, 500 µs were about 5 mSv/h at 80 cm from the axis and 254 mSv/h at contact. More details on the radiation measurements can be found in Ref. [2].

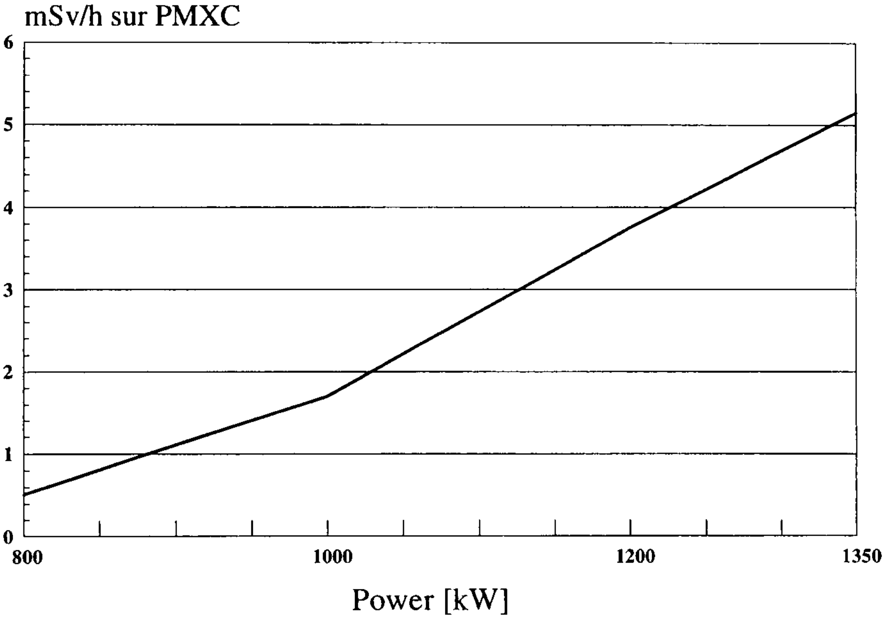

Figure 5 : Dose rate as function of power to the cavity (500 µs), measured at 80 cm from the axis.

6. FIELD EMISSION MEASUREMENTS

The high field levels reached during the tests led to high amounts of field emission current (dark current). To measure the dark current, first of all was taken a plot of the measured input cavity power as function of the square of the voltage measured at the monitoring loop. Without dark current, all the power is used for establishing the gap voltage, and power is proportional to voltage squared (the coefficient for the effective voltage being the inverse of the shunt impedance). When at high voltages dark current appears, the electrons are accelerated over the cavity gaps and take from the generator an additional power P=I*U, I being the overall electron current and U the average gap voltage. Electron transit time factor is 1 for the gap size and frequency of our test. Figure 6 shows the power vs. U squared plot of a measurement done on 27.11. We can see the deviation from the straight line due to field emission for input power beyond 800 kW.

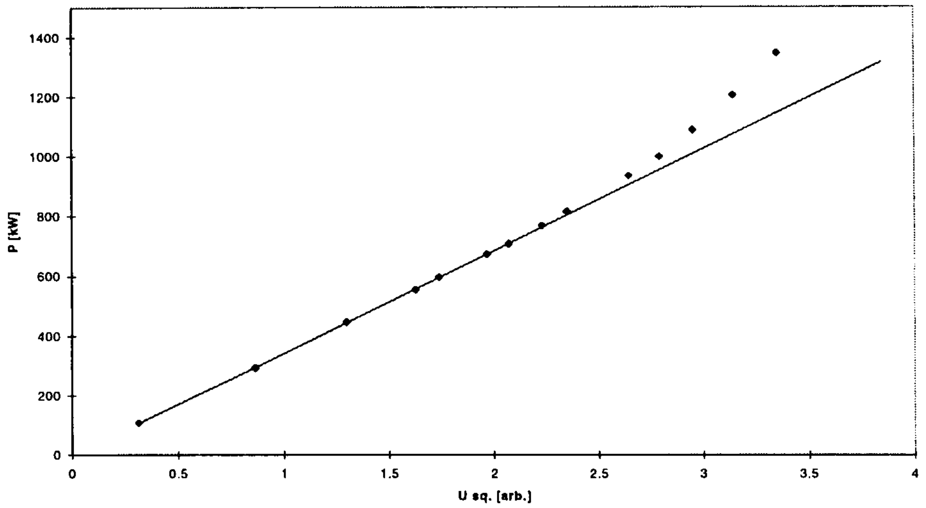

Figure 6: Input Power vs. Voltage squared (27.11, pulse length 200 μs).

From the slope of the straight line P vs. U^2 for low power, one can calculate the power going to dark current for each measurement point. This is the difference between the theoretical power, calculated from the straight line, and the real power. Dividing the power by the average gap voltage, we obtain the overall amount of dark current. Figure 7 shows three measurements of dark current as function of cavity voltage, in units of the nominal Pb27+ voltage, taken at the end of the conditioning process for the three different pulse lengths. In all the cases, appreciable dark current emission starts at 1.4-1.5 times the nominal voltage, and then it rapidly grows with the voltage, up to currents of hundreds of mA (250 mA was the highest measured current).

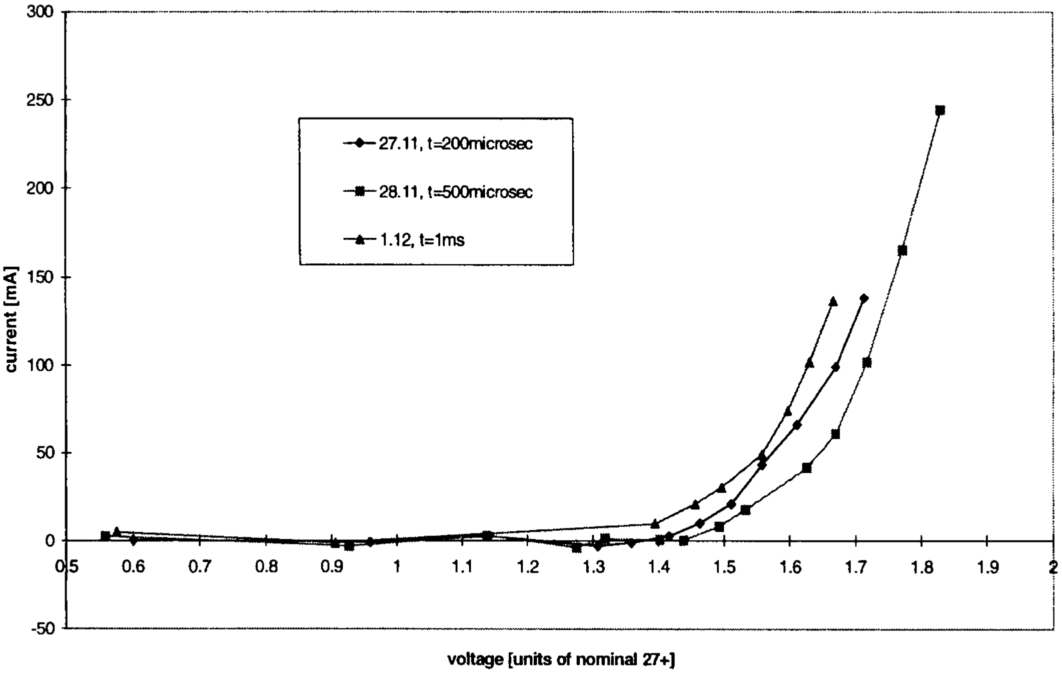

Figure 7: Overall Field Emission Current vs. Field level (units of nominal).

We can re-draw the dark current measurements in the form of the "Fowler-Nordheim" plot (Figure 8, for the three pulse lengths), in order to calculate from the measured data the value of the surface field enhancement factor beta. As can be seen from the curves, this did not change appreciably during the conditioning process, remaining always in the range 100-114, corresponding to clean surfaces. For comparison, values measured with the same technique on the CERN RFQ2 at different moments ranged between 67 - very clean - and 920 - heavily polluted [3]. As expected, the conditioning process did not change the surface field enhancement beta, corresponding to the slope of the curve, but instead changed the intercept, proportional to the overall emission or to the number of emitting spots on the surface. Between the first two measurements (from 200 µs pulse length to 500 µs) we see a drastic reduction in the emitted current. Instead, when the pulse length was further increased to 1 ms, the emission went drastically up again (curve of 1.12).

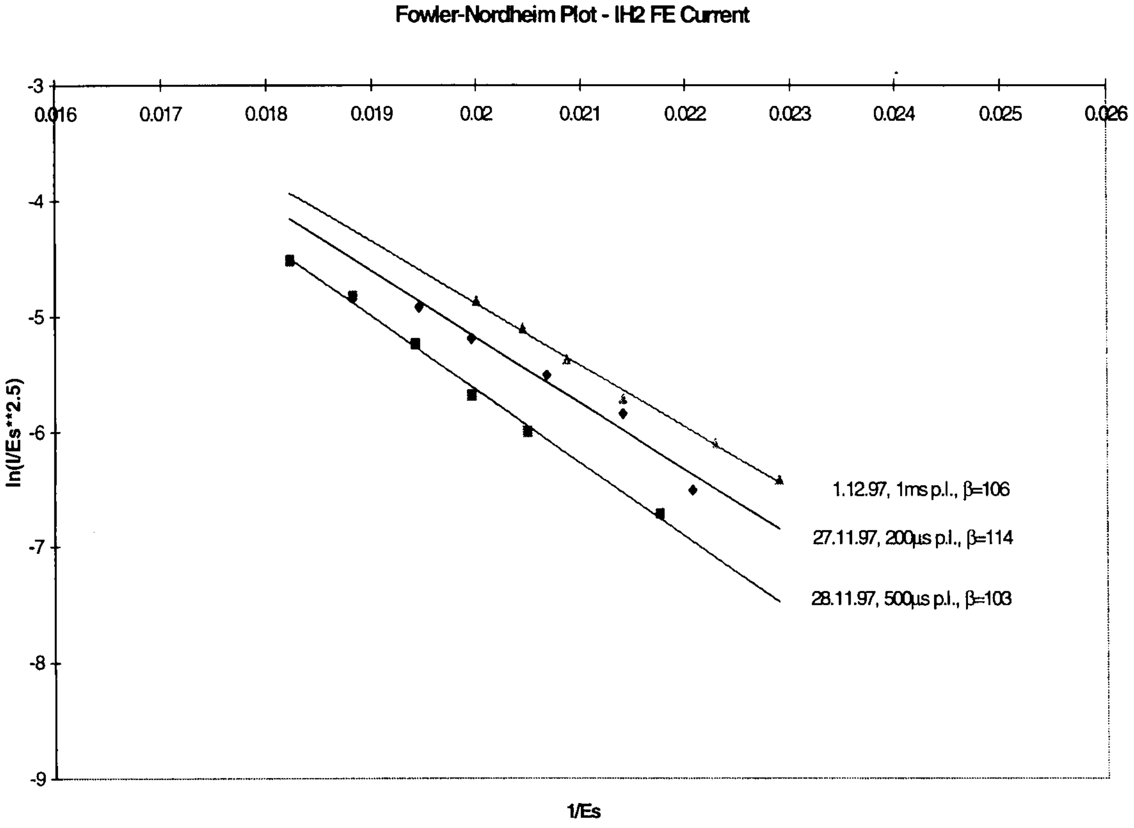

Figure 8: Fowler-Nordheim plot for field emission from tank2 at three different moments during the conditioning process.

7. REFERENCES

[1] R. Scrivens, High Power Measurements and Segmented Phase Probe Improvements on Linac3, PS/HP/Note 97-08 (MD).

[2] J.-M. Hanon, Rapport de Surveillance Radiation, RSR/PS/98-02/jmh.

[3] M. Vretenar, Field Emission Measurements on RFQ2 and Re-calibration of the Vane Voltage, PS/RF/Note 97-11 (MD).