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HIGH POWER CONDITIONING OF THE 202 MHZ IH TANK 2 AT THE CERN LINAC3

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High accelerating gradients are very interesting for future machines, and, in particular, for high-current heavy-ion linac projects like the "Inertial Fusion Driver". In order to explore the maximum field achievable in an Interdigital-H type structure (IH), an experiment has been carried out at CERN with the Lead Ion Linac (Linac3). After the 1997 run, the RF amplifiers were rearranged in order to allow the feeding of the IH Tank number 2 (1.54 m long, 28 gaps, frequency of 202.56 MHz) with up to 2 MW pulsed RF power. After two weeks of conditioning at pulse lengths varying between 200 μs and 1 ms with a constant pulse repetition rate of 0.8 Hz, the maximum effective accelerating gradient achieved was 10.7 MV/m. This corresponds to a local field maximum of 75 MV/m, and to fields in excess of 50 MV/m (3.5 times the Kilpatrick limit) on large portions of the drift tube surfaces. This paper reports the conditioning procedure used, the measurements of field emission current at different voltages and pulse lengths, the determination of the surface field enhancement factor as well as the calculation of the electric field distribution for the gap with the highest surface fields.

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Abstract

High accelerating gradients are very interesting for future machines, and, in particular, for high-current heavy-ion linac projects like the "Inertial Fusion Driver". In order to explore the maximum field achievable in an Interdigital-H type structure (IH), an experiment has been carried out at CERN with the Lead Ion Linac (Linac3). After the 1997 run, the RF amplifiers were rearranged in order to allow the feeding of the IH Tank number 2 (1.54 m long, 28 gaps, frequency of 202.56 MHz) with up to 2 MW pulsed RF power. After two weeks of conditioning at pulse lengths varying between 200 µs and 1 ms with a constant pulse repetition rate of 0.8 Hz, the maximum effective accelerating gradient achieved was 10.7 MV/m. This corresponds to a local field maximum of 75 MV/m, and to fields in excess of 50 MV/m (3.5 times the Kilpatrick limit) on large portions of the drift tube surfaces. This paper reports the conditioning procedure used, the measurements of field emission current at different voltages and pulse lengths, the determination of the surface field enhancement factor as well as the calculation of the electric field distribution for the gap with the highest surface fields.

1 SET-UP

For the normal Pb^{27+} operation of Linac3 [1], the IH Tank 2 requires 320 kW of RF power, which corresponds to a voltage gain of 9.09 MV. Its amplifier can deliver 800 kW, and during a test in 1996 the cavity was easily conditioned up to this power [2].

In order to increase the output power, a special amplifier arrangement has been prepared at the end of the 1997 Linac3 run. The tube TH170R, used in the final stages for Tanks 2 and 3, can deliver power levels up to 2.5 MW at a low duty cycle if enough power from the driver stage is available. By inserting the final amplifier stage of Tank 3 temporarily into the Tank 2 chain, between the driver and the final stage, more than 2 MW output RF power became available. The maximum pulse length in this configuration was 1 ms. This corresponds to a duty cycle of 0.08% at the Linac3 repetition rate of 0.8 Hz.

2 CONDITIONING

A two week period was made available for the high power tests, before the CERN winter shutdown. Part of this already short time was used for cabling the new amplifier arrangement, for improving the radiation safety of the installation (high X-ray levels were reached during the tests), and finally for some repairs to the amplifier electronics. The effective time available for conditioning amounted to 230 hours (i.e. slightly less than 10 days).

First of all, the power was gently increased with a pulse length of 200 µs. Breakdowns with associated strong degassing started from about 700 kW. The pumping rate of the vacuum system finally determined the acceptable number of breakdowns and therefore the speed of the conditioning process. Under normal conditions, the vacuum in Tank 2 is the best of the Linac3 complex, $4{\cdot}10^{-9}$ mbar. During the conditioning, it was noticed that the cavity was not able to recover from a series of breakdowns when the pressure entered in the 10^{-6} range, thus the power was reduced in order to stay within the 10^{-8} and 10^{-7} mbar region. The conditioning was done manually, but a 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 1 shows the integrated number of breakdowns (pulses where the cavity could not reach the programmed voltage) and the corresponding pressure during one night (15 hours at 780 kW) of the pre-conditioning phase.

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, a power of 1.21 MW was reached with only occasional breakdowns, however with dark current emission absorbing about 6% of the input RF power. At this point, instead of trying to push the field higher, the pulse length was increased to 500 µs. After 48 hours of reconditioning starting from 1 MW, the maximum stable level reached was as high as 1.3 MW. Beyond this input power level heavy sparking started with high degassing. Next, the pulse length was further increased to 1 ms and the conditioning restarted at 800 kW and reaching

1.2 MW after 3 days. Increasing the field beyond this level led again to heavy sparking with an almost immediate degradation of the vacuum.

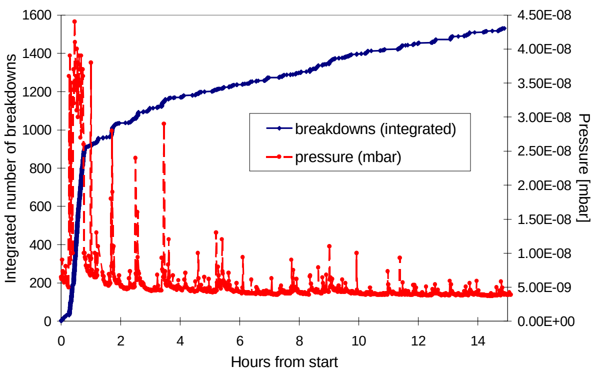

Figure 1: Integrated number of breakdowns and pressure during 15 hours pre-conditioning at 780 kW.

Figure 2 shows the power delivered to the tank as a function of time from the start of the tests. Table 1 gives the maximum gap voltage achieved, in units of the nominal voltage for Pb^{27+}, and the corresponding surface electric field at two positions, on the drift tube face and on the edges (see next Section).

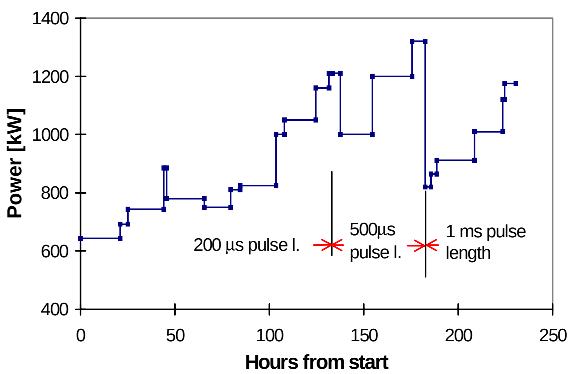

Figure 2: Conditioning history (RF power vs. time).

Table 1: Voltage and peak surface field achieved.

Pulse length	Voltage	*E*-field on tube	Max. *E* on tube	Eff. tank acc. field
[µs]	units of Pb^{27+} voltage	[MV/m]	[MV/m]	[MV/m]
200	1.71	51	70	10.1
500	1.82	54	75	10.7
1000	1.67	49	69	9.8

The radiation level (X-rays) during the tests was permanently monitored. The dose rates measured at 1.35 MW and 500 µs were about 5 mSv/h at 80 cm from the cavity axis and 2543 mSv/h at the tank surface [3].

3 SURFACE FIELD DISTRIBUTION

Figure 4 shows gap voltage and on-axis field distributions in Tank 2, derived from a bead-pull measurement scaled to the maximum voltage achieved during the tests (1.82 times the nominal). The electric field distribution in gap number 9, where the voltage is maximum, has been calculated with the code MAFIA to find the value of the surface field reached in the cavity during the tests. Figure 5 shows the calculated electric field in the plane of the stems and the value of the electric field at four representative points on the drift tube surface.

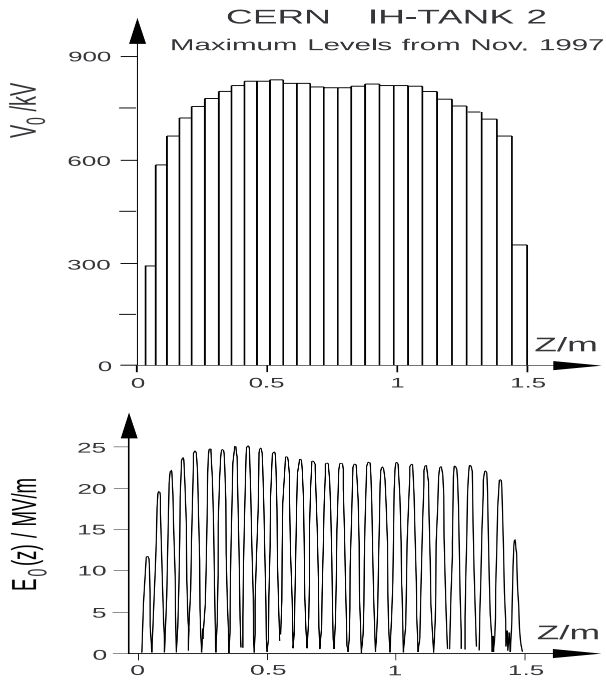

Figure 4: Voltage and electric field distribution (Tank 2).

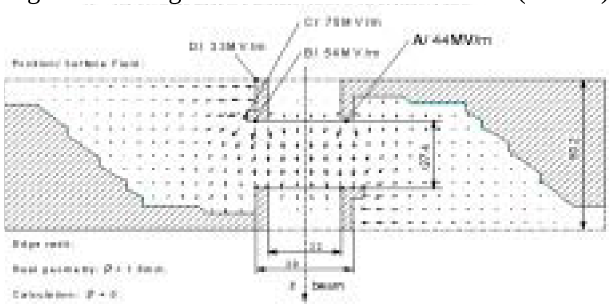

Figure 5: MAFIA calculation of field distribution in gap number 9 for 830 kV gap voltage.

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 (tube edge). At the other points, the values should be realistic, since they are calculated far enough from the square edges, as compared to the mesh step of 0.6 mm. Thus the field at point B can be taken as representative of the field on the drift tube face, while point C represents a maximum field reached only on an area of about 0.5 cm^2 per drift tube.

In conclusion, fields of about 54 MV/m were reached on the drift tube face (~ 6 cm^2 per tube) in more than 20 gaps. This corresponds to 3.5 times the Kilpatrick level at 202 MHz (14.8 MV/m).

4 FIELD EMISSION MEASUREMENTS

The high electric field reached during the tests led to high levels of field-emitted current (dark current). The dark current level was measured at regular intervals by monitoring the cavity voltage for different RF input levels.

Without dark current, the power is proportional to the voltage squared, the coefficient being the inverse of the shunt impedance. When at high voltages dark current appears, the electrons are accelerated over the cavity gaps and extract an additional power $P=I\times U$ from the generator, I being the overall electron current and U the average gap voltage. The electron transit time factor is unity for the gap size and frequency of this case. When plotting P vs. U^2, the deviation from a straight line at high power gives the power driving the dark current; the dark current value is obtained by dividing this power by the average gap voltage. Figure 7 shows the measured dark current as a function of cavity voltage in units of the nominal Pb^{27+} voltage, at the end of the conditioning process for the three different pulse lengths. In all cases, appreciable dark current emission starts at 1.4 to 1.5 times the nominal voltage, and then rapidly grows with voltage. The highest dark current measured absorbed 9% of the input RF power.

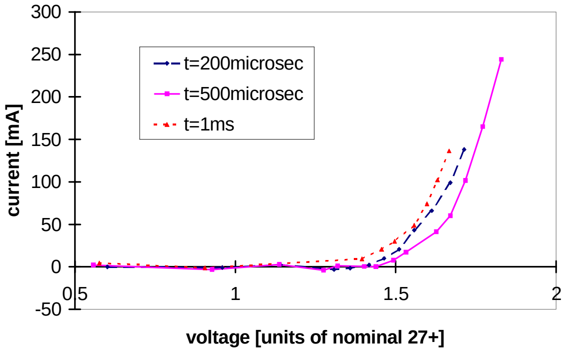

Figure 7: Overall field emission current vs. field level (units of nominal) for three pulse lengths.

The three measurements can be re-drawn in the usual "Fowler-Nordheim" form $\ln(I/E_s^{2.5})$ vs. $1/E_s$ (Figure 8), where field emission is represented by a straight line with a slope equal to the inverse of the surface field enhancement factor beta.

From the curves, it can be seen that β did not change appreciably during the conditioning process, being always between 100 and 114, values that indicate clean electrode surfaces. For comparison, β measured with the same technique on the CERN RFQ2 at different times ranged between 67 - very clean - and 920 – heavily polluted [4]. As expected, the conditioning process changed the intercept of the straight line, which is proportional to the overall emission, i.e. to the number of emitting spots on the surface. Between the first two measurements (200 µs and 500 µs pulse length) there is a reduction in the emitted current. When the pulse length was further increased to 1 ms, however, the emission went up again.

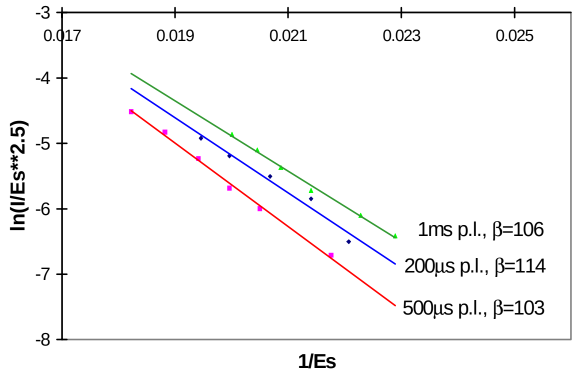

Figure 8: Fowler-Nordheim plot for the cases of Fig 7.

5 CONCLUSIONS

IH cavities of this type, with small diameter drift tubes, can stand fields of 50 MV/m (3.5 Kilpatrick) on large fractions of the drift tube surfaces, for low duty cycles and at pulse lengths up to 1 ms. Local maxima can be as high as 75 MV/m. These field levels were achieved after only a few days of conditioning with a cavity which has been in routine linac operation since 1994. Field emission was observed at surface field levels above 45 MV/m. Higher "clean" levels may be reached by applying an extended RF conditioning concept.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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