High Gradient Experiments with Nanosecond Pulses

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Abstract

Within the framework of studies related to pulsed accelerating techniques, in particular for the switched power principle, the voltage hold-off for very short pulses has been measured for different materials. Following a presentation of the subject and the requirements, a brief description of the experimental set-up is given. So far gradients of 900 MV/m have been obtained with pulses of two nanoseconds and flat electrodes. The results are compared to measurements based on different experimental techniques.

I. INTRODUCTION

Future lepton linear colliders, will require much higher accelerating gradients than the ones actually used, in order to obtain a substantial reduction in length as compared to designs based on present technologies. At lower energies, i.e. for high brilliance guns, higher gradients may help to diminish space charge problems.

For conventional r.f. accelerating structures the tendency goes to shorter wavelengths, which are more favourable for voltage hold-off. Different schemes have been proposed to achieve the high gradients. The switched power principle [1] suggests using very short pulses to excite a passive transformer network for producing pulses of 1 MV during 10 ps into 1 mm wide accelerating gaps. The realization presents a series of challenges and we have so far investigated the generation of short pulses and the related voltage hold-off problems.

II. GENERAL CONSIDERATIONS

A. Short pulse generation

The idea is to excite a radial transmission line by discharging a photocathode with a fast laser and to amplify the resulting pulse by adiabatic impedance transformation, rather than switching the high voltage directly into the accelerating structure.

According to a study of the transformer effect with a scale model, a gain in voltage by a factor of 20 seems quite feasible [2]. By switching pulses of 50 kV amplitude into the structure one will get 1 MV at the output. We have not yet got the expertise for the very fast laser switching, but in the case of very high current discharges there may be further restrictions for the gain due to saturation effects and the intrinsic impedance of the switch itself.

B. Voltage hold-off

The highest surface fields will have to be held for only 10 ps in the center of the transformer structure. Another critical place is the input to the structure, where the switch voltage must be held prior to the laser discharge, but possibly only for a few nanoseconds.

Any investigation into the voltage hold-off problems for the very fast pulses in the center requires a transformer network operating with the fast laser switch. We therefore prefered to study first the breakdown problems with more conventional instrumentation in the nanosecond domain. This will correspond to the charge of the laser switch and probably allow for extrapolation to shorter pulse lengths.

C. Experimental approach

The few experimental results available so far on breakdown limits for nanosecond pulses suggest that gradients of the order of 500 MV/m should be possible [3], depending on the cathode material. Most of the experiments have been done with pointed needle electrodes in order to achieve the required high fields and by measuring the delay to breakdown when submitted to sufficiently long high voltage pulses. The interpretation of these results has to account for changes in the effective cathode radius due to thermal effects during the discharge. Further the small needle points are not really representative for the required large area switching of the switched power principle.

We therefore intended to examine large flat electrodes, at the expense of having to deal with very small gaps to obtain the high gradients. Well defined short pulses are used in order to avoid excessive surface damage.

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III. BREAKDOWN MEASUREMENTS

A. Experimental set-up.

We use a coaxial transmission line, about one meter long and 110 mm in diameter, with the outer conductor serving as the vacuum vessel. The line is closed by two impedance-matched glass windows. The operational pumping is done with an ion pump. The experimental spark gap is inserted in the middle of the line and connects via r.f. spring contacts to the inner and outer conductor.

Openings for pumping ports, gauges, broadband voltage probes and observation windows are matched in impedance to give less than 2 % perturbation at 1 GHz. Only the test gap causes 6-7 % reflections because of its relatively high capacitance. We have further tried to keep all possible mismatches sufficiently far away from the test electrodes, in order to avoid perturbations disturbing the breakdown signal.

A coaxial generator of the Blumlein type, loaded by a capacitor bank discharge, delivers 12 kV pulses into the coaxial structure. The rise and fall times are 200 ps and the half-height pulse width is 2.2 ns.

B. The spark gap

The test gap forms a compact preassembled block, consisting of the interchangable flat cathode and the isolated anode.

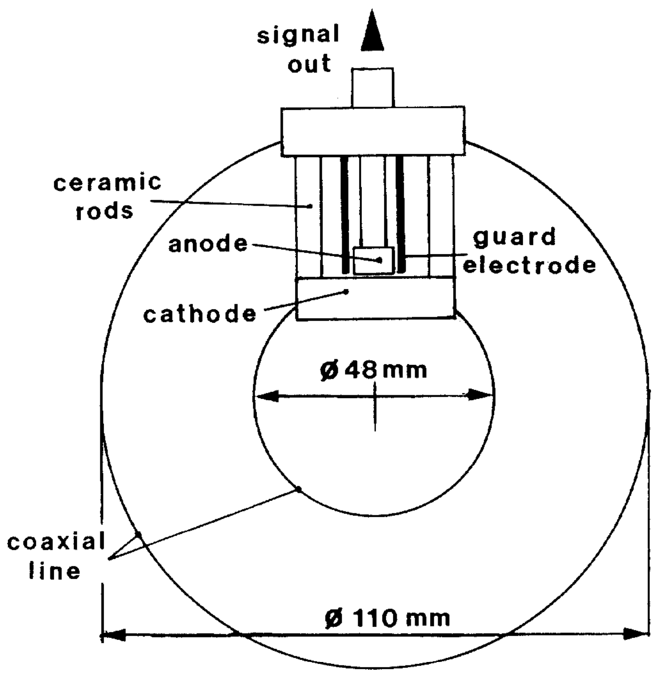

Fig. 1 Schematic cross section of the test gap

The latter is surrounded by a guard electrode to ensure a homogeneous field in the test gap. The surface exposed to the high voltage has an area of 0.5 cm^2 and the gaps can be adjusted to distances as small as 10 μm. The signal from the anode is output via a coaxial UHV feedthrough.

C. Signal observation

The detection of breakdowns is done by observing the current collected by the anode with a fast oscilloscope. Due to the large area of the test gap there is unfortunately already a strong capacitive coupling of the high voltage pulse to the anode, even when there is no breakdown.

In the beginning this has raised some problems to distinguish the real breakdowns from the signal pick-up. A differential method using a second probe with a similar time constant as the anode proved to be useful to eliminate the residual signal. In the meantime we have found out how to distinguish the signature of breakdowns from the combined signal.

IV. EXPERIMENTAL RESULTS

The measurements for a wide range of cathode materials are summarized in Fig.2 and compared to the results from Mesyats and Rohrbach [4] to give a consistent picture for pulses ranging from nanoseconds to microseconds.

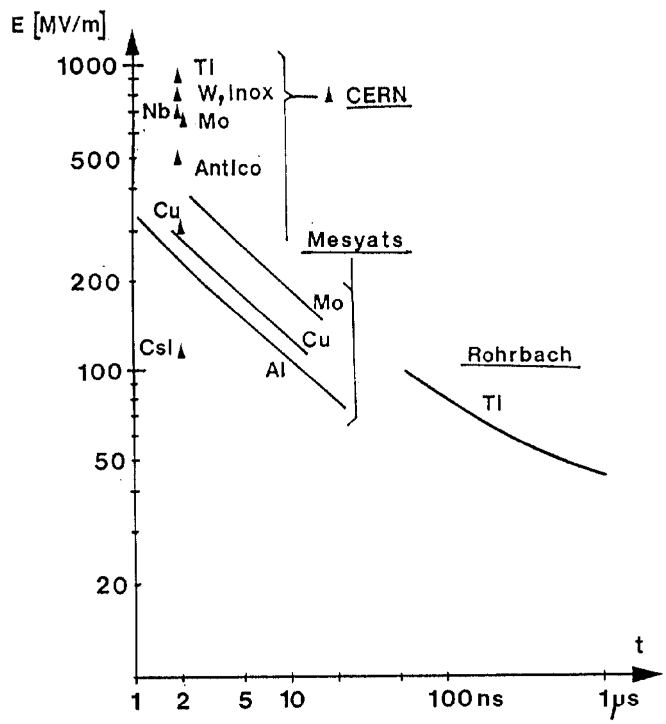

Fig. 2 Results of measurements

The values indicated correspond to the threshold for gradients hold with no breakdown after the initial conditioning of the electrodes.

Most of the measurements have been done with 10 μm gaps, but despite the tricky adjustment the results are well reproducible. For materials with lower breakdown limits we could also prove the surface gradients to be constant for gaps as large as 50 μm.

Our breakdown fields are generally slightly higher than the results obtained by Mesyats, except those for copper cathodes. But both sets of results are in reasonable agreement, if one takes into account the different measurement methods. There may also be a difference in the composition of materials. For example, we used electrodes made from aluminium and titanium alloys instead of pure metals. Probably we also had better vacuum conditions (10^{-7} mbar). Other explanations for the difference are under consideration, like the influence of surface or thermal treatments of cathodes prior to testing, or the possible impact of the anode material on the cathode initiated breakdown.

An analysis of the electrode surfaces by secondary electron microscopy has shown that the breakdowns during conditioning are equally spread over a large area of the gap, proving the relative flatness of the electrodes. Breakdown currents may amount to several hundred amperes and can produce craters of the order of 5 to 20 μm in diameter and a few μm deep. Although the surfaces submitted to breakdowns look quite uneven at the microscopic level, there is no obvious reduction in the voltage hold-off.

In addition, we have observed a material transfer between the anode and cathode, which is not yet completely understood. In a few cases local fusion has led to short circuits between the electrodes. This was generally found to be due to accidental discharges of the capacitor bank directly into the test gap, caused by internal sparking in the Blumlein generator.

V. CONCLUSIONS

The present results confirm that the high gradients required for the switched power principle can be held. But at present the complexity and the low quantum efficiency of the laser switching prevent the application of the switched power principle on a large scale.

We can further conclude that these high fields can for some metals already be achieved with nanosecond pulses. This opens the opportunity for a pulsed device using "slow" switching, possibly without using expensive fast laser technology.

But the longer pulses also have their disadvantages, because of the increased stored energy in the pulse forming networks and the physical size of the impedance transformer, as the dimension of the latter is proportional to the pulse length.

Therefore, both the fast and the slow version of the switched power concept are for the time being mainly of interest for the design of a single or few stage device, like a high brillance electron gun. This assumes that the stringent laser requirements or the bigger size of the slow transformer can be outweighed by a significant reduction of space charge effects during extraction.

VI. REFERENCES

[1] W. Willis "Laser Acceleration of Particles," *AIP Conf. Proc. No.130, page 421, 1985*

[2] S. Aronson et al. "Model Measurements for the Switched Power Linac," *Proceedings of the 1987 IEEE Particle Accelerator Conference, Washington, D.C., Vol. 1, page 121-123*

[3] G.A. Mesyats, "Pulsed Electrical Discharge in Vacuum," *Springer Verlag, Berlin-Heidelberg, 1989*

[4] F. Rohrbach, "Isolation sous vide," *CERN yellow report 71-5 (TC-L), 1971*