Measurement of breakdown turn-on time in DC spark setup for CLIC

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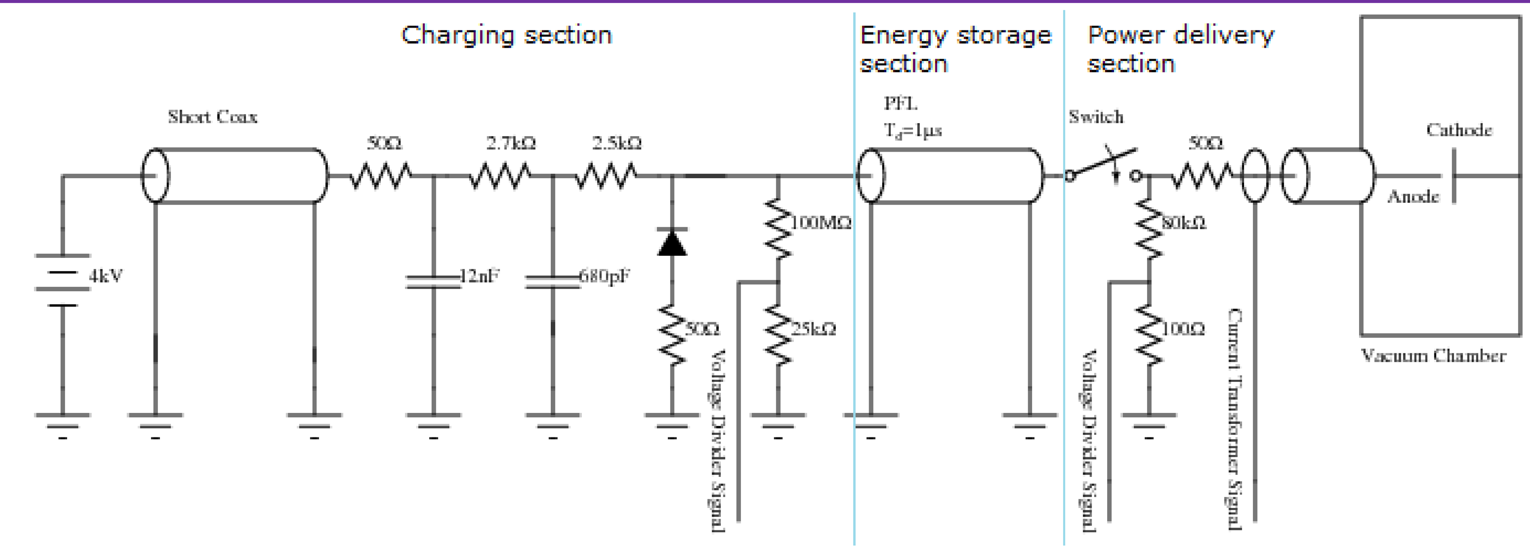
High Repetition Rate System

At CERN there are two “DC Spark Systems” which are used by the CLIC project to investigate the phenomenon of electrical breakdown in vacuum. The study of breakdown is of critical importance for the CLIC project which will need to be able to operate thousands of accelerating structures with surface fields in excess of 200MV/m with fewer than 10-6 breakdowns per pulse per meter.

In RF tests, a statistically significant BDR (breakdown rate) of 10−7 1/pulse/m can be achieved in around 1000 h of testing at a 60Hz repetition rate.

The recently installed HRR (High Repetition Rate) system uses a solid state switch and can operate at 1 kHz, which will enable BDR measurements of 10−10 1/pulse within a reasonable testing time.

The HRR circuit consists of three parts: the charging section; the energy storage section; and the power delivery section. The energy for the breakdown is stored on the PFL (Pulse Forming Line) a 200m long coaxial cable.

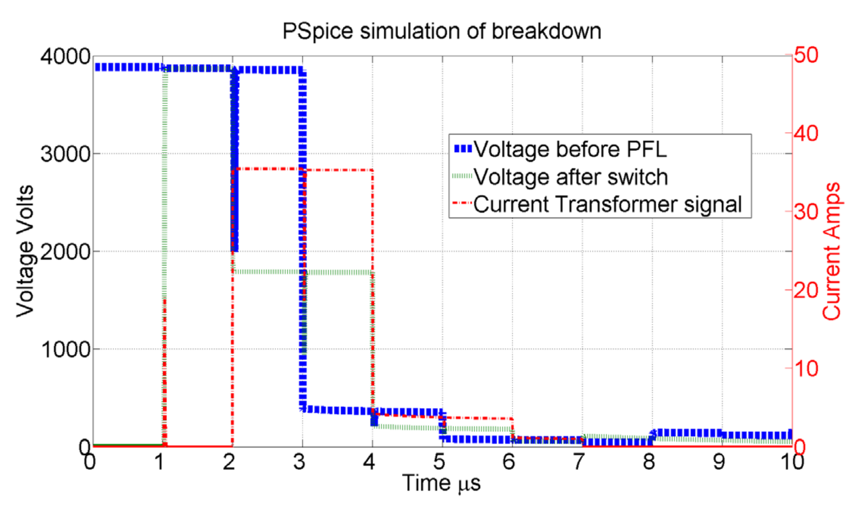


The circuit diagram of the HRR system. It can be thought of as consisting of three parts: the charging section; the energy storage section; and the power delivery section.

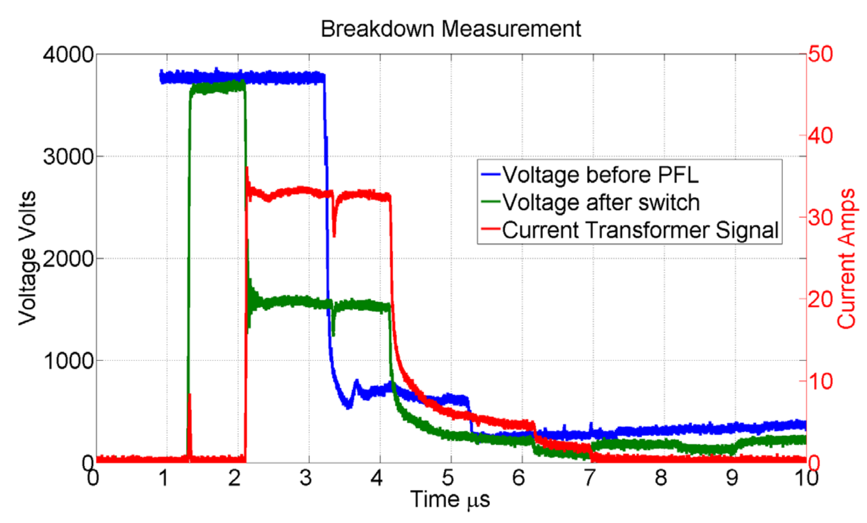
Understanding the Circuit

In order to ensure that the HRR circuit was well understood we modeled a simplified version in PSpice. Simplifying assumptions include the characteristics of the MOSFET switch the lack of various stray impedances and the resistance of the PFL which was set to the measured DC value. The spark gap was also modeled as a switch which was closed for breakdown and open otherwise.

Despite the simple model used the agreement between the simulations and measurements was generally good with the same basic features. All the transitions in the real system were generally less sharp than in the simulation and the amplitudes of the reflections were larger and of shorter duration, this is likely due to stray impedances and other bandwidth limitations .



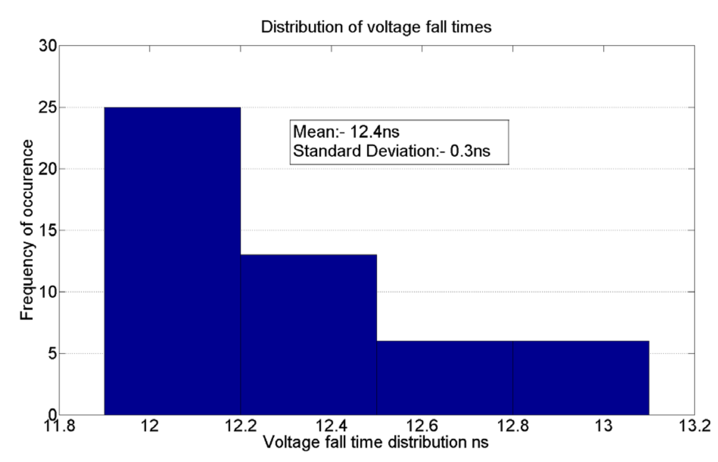
PSpice simulation of the HRR circuit during a breakdown. The switch is closed at 1us and the breakdown occurs at 2us.



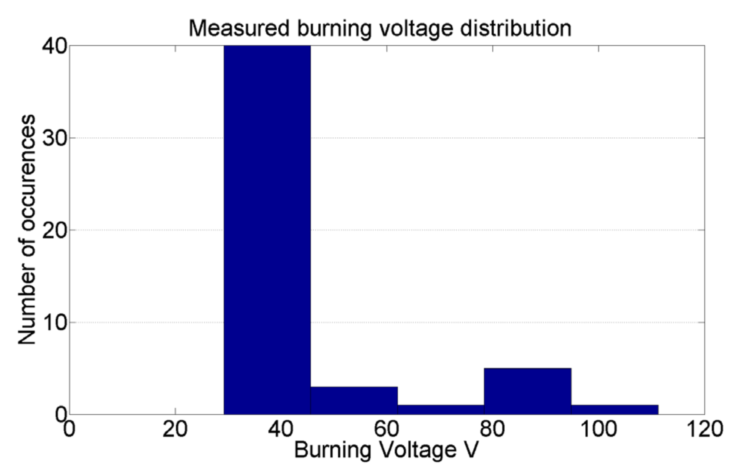
Measured voltage and current signals in the HRR circuit during a breakdown. The switch is closed at 1us and the breakdown occurs at 2us.

Measured Turn on Time and Burning Voltage

An error function was fitted to the falling edge of the voltage and the 90% to 10% fall time was found to be around 12ns. The burning voltage was also measured and it was found to be around 40V which is slightly higher than the 20V or so which is usually found in the literature[1].



Distribution of the time taken for the voltage to fall from 90% to 10% at the onset of a breakdown.



Distribution of the measured burning voltage during a breakdown.

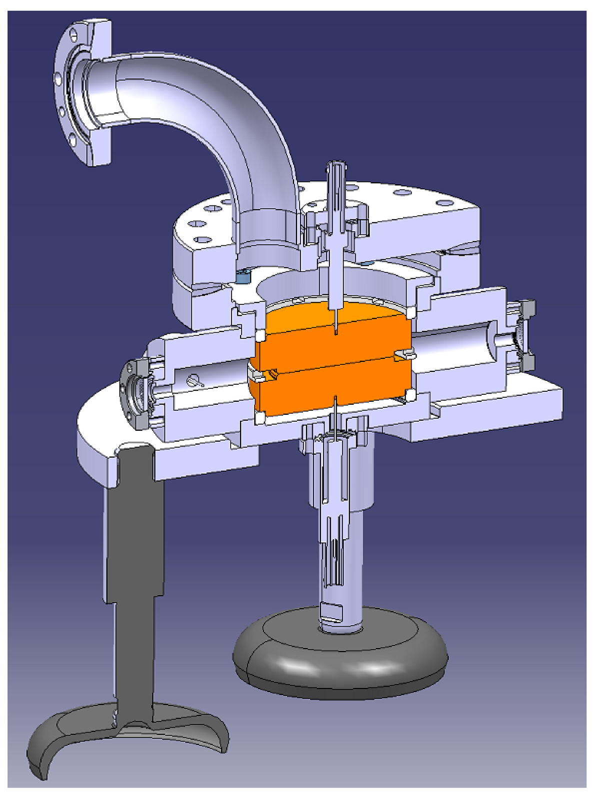
Why measure the turn on time?

Results of the RF tests indicate that low group velocity, and consequently narrow bandwidth structures are able to sustain much higher surface fields than high group velocity, large bandwidth, structures [1][2]. This dependency is captured by the high power limits P=C and Sc presented in [2]. Reference [2] also suggests a physical model to explain the origin of these limits and further study has led to the idea that the process which governs the turn on time is the instantaneous power flow available to feed the breakdown during its onset. In other words a high group velocity structure could more quickly replenish local energy density absorbed by a growing breakdown leading to faster turn on times.

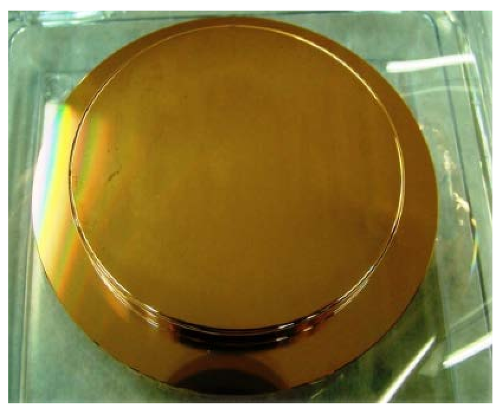
An accurate measure of the rise time of breakdowns in the DC systems under electrostatic conditions is an essential precursor to understanding whether the transient response of RF systems to the breakdown currents determine breakdown limits.

Fixed Gap System

A new system has been built which has a much larger electrode surface and which the gaps are at a fixed distance. A larger surface area mean that most of the breakdowns will occur on a surface which has not yet seen a breakdown as is the case in high power RF tests of accelerating structures. They system is also small enough that the entire apparatus can be placed within the aperture of a powerful 2 Tesla normal conducting magnet we have here at CERN. This will enable us to investigate the effect an external magnetic field has on the breakdown rate.



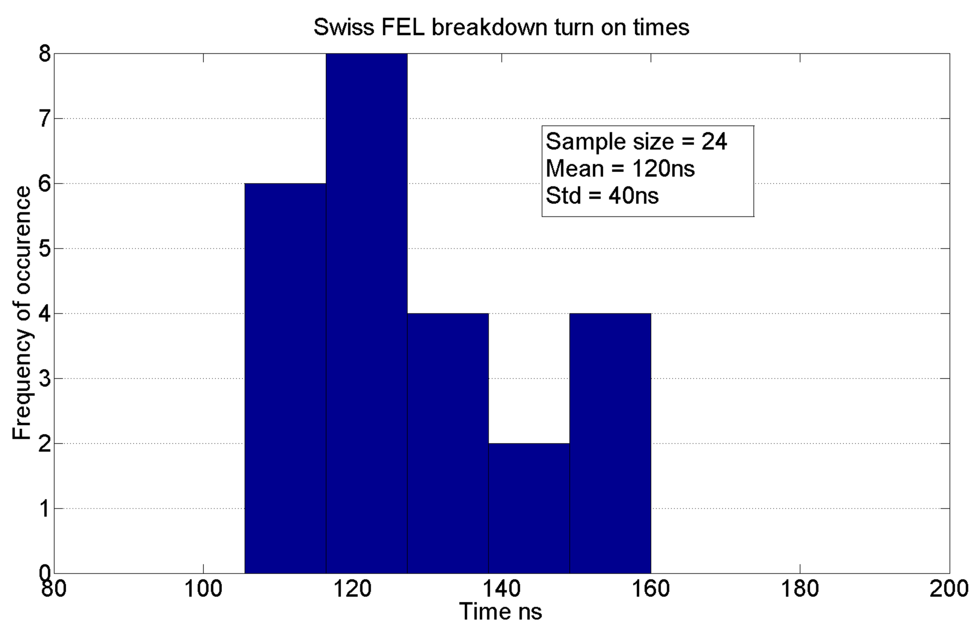
There is little wasted space so the size of the system can be kept very small despite the comparatively large size of the anodes. Four antennas are included in the design to pick up the radiation from breakdowns.



The surface of the electrodes are 80mm in diameter and have a surface tolerance of <1um. The picture on the right shows the high precision turning.

PSI Swiss FEL Breakdown data

Analysis of breakdown data from the Swiss FEL project is also under way so that the results may be compared both to the results of the x-band CLIC accelerating structure tests and the DC spark system results. More analysis is yet to be done but an initial investigation of the fall time of the demodulated transmitted RF signal seems to indicate that the turn on time of the breakdown in this case is slower than both the X-band and DC case.



A histogram of the fall time of the demodulated transmitted RF power. When a breakdown occurs in an accelerating structure, the RF power can not be transmitted and is instead reflected. The fall time of the transmitted power is taken as indication of the breakdown turn on time. It appears to be much slower than in the DC case.

References

[1] A. Anders 2001, “Energetics of vacuum arc cathode spots”, Applied Physics Letters, vol. 78, no. 19, pp. 2837-2839.

[2] C. Adolphsen 2005, “Advances in Normal Conducting Accelerator Technology from the X-Band Linear Collider Program”, PAC 2005 pp.204-8.

[3] A. Grudiev, S. Calatroni and W. Wuensch 2009, “New local field quantity describing the high gradient limit of accelerating structures”, PRSTAB, vol. 12, no. 10, pp.102001-1 -102001-9.

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