Large electrode conditioning measurement, first results

28.4.2015

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Overview

Conditioning test using new electrodes fresh out of structure treatment was launched on 16.4.2015, starting from 1000 V with a 60 µm gap, 5 µs pulse length

Up until latest analysis (presented herein), the system has:

- -Had 483 million voltage pulses
- -Had 6248 breakdowns
- -Run 9444 voltage feedback algorithm iterations
- -Gone from 1000 V to 2398 V at roughly constant BDR

Two random interruptions of the run have happened so far, longest downtime was about 36½ hours.

The apparent poor quality of the electrodes, caused by improper handling during the treatment, has not yet caused any issues that can be discerned from the data.

Conditioning algorithm

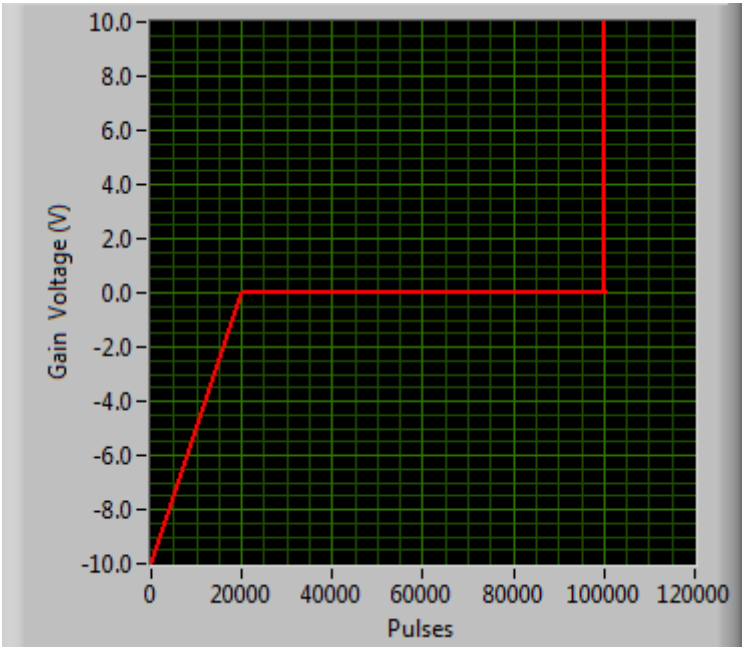
Each iteration, the system sends voltage pulses continuously, ramping up the voltage to its set value over the first ~1500 pulses. The pulsing stops when the system has a breakdown, or has had 100000 pulses without a breakdown.

After stopping, it adjusts set voltage accordingly:

-If it had an early breakdown (before 20000 pulses), it decreases voltage in proportion to (20000 – “nr of pulses”), maximum –10 V

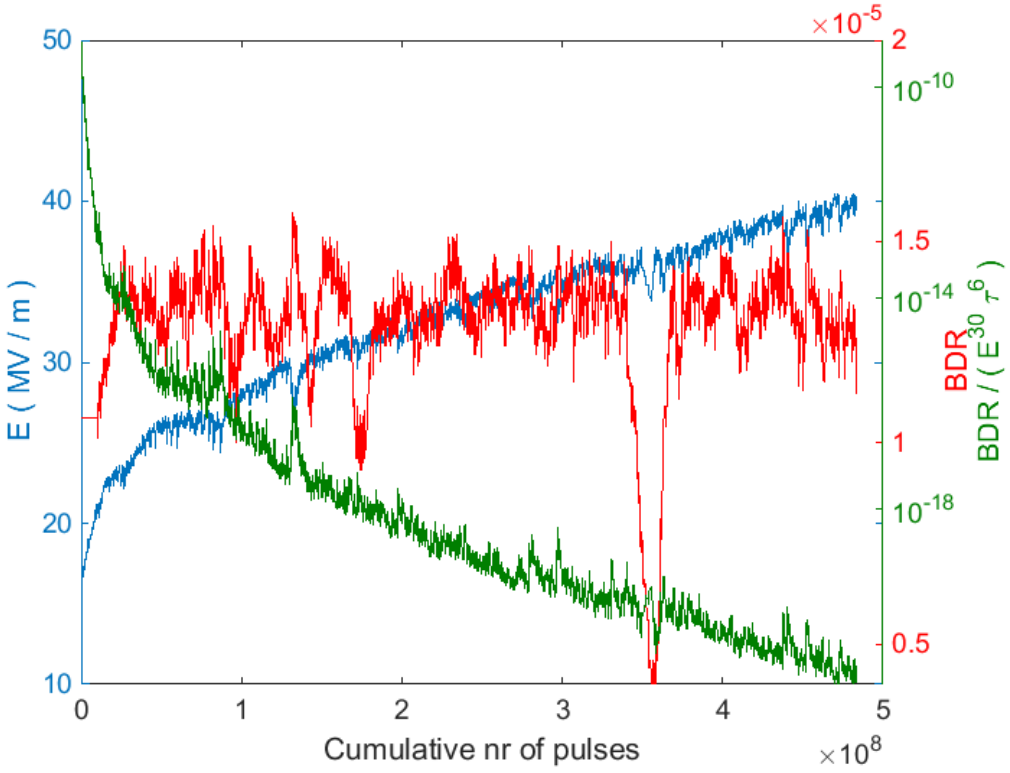
-If it had a late breakdown (after 20000 pulses), no change to the voltage

-If it had a timeout (reached 100000 pulses without breakdown), increase voltage by 10 V



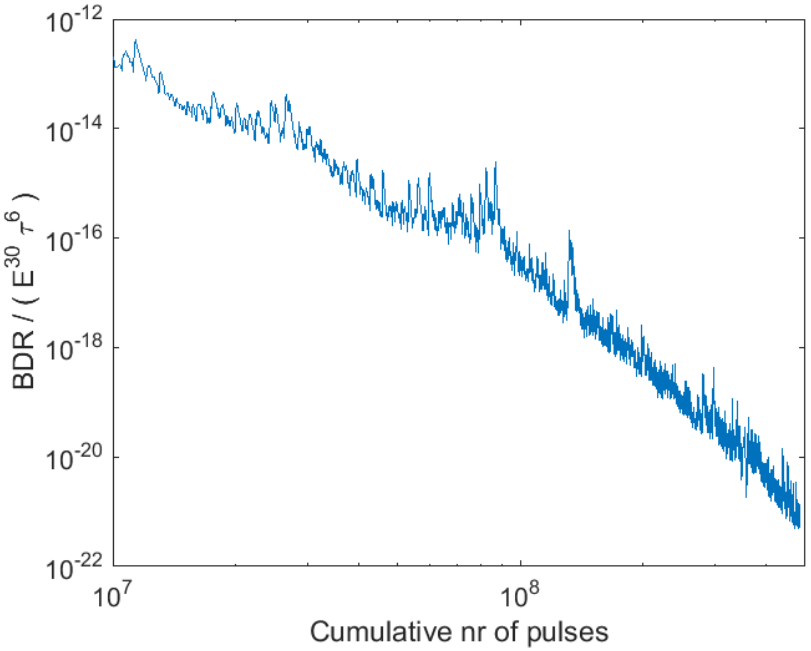
The system also tracks overall breakdown rate by a sliding window of the last million pulses. If BDR is more than a cap value (1e-4), voltage will not be increased on a timeout

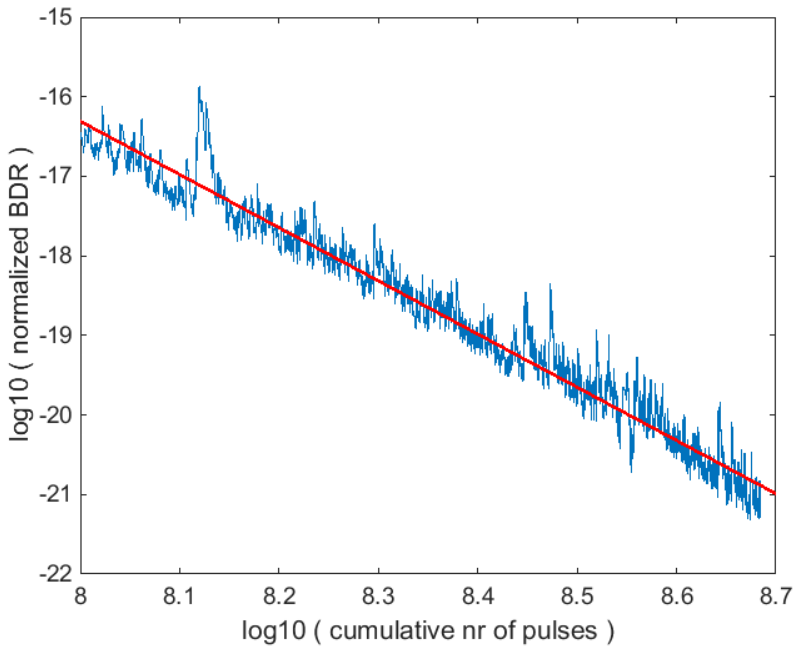
Overall conditioning history



Evolution of electric field, breakdown rate and normalized breakdown rate is shown here. Conditioning progress is remarkably steady so far, with only small, short-term fluctuations in normalized BDR

Conditioning rate





Multiple RF structures have shown conditioning behavior where normalized BDR is linear against cumulative number of pulses in a log-log plot. It seems to be so in our case as well, from 1e8 pulses onward, though it's quite early to say (we have been linear over less than one order of magnitude of x-data!). Log-log linefit had a slope of -6.69

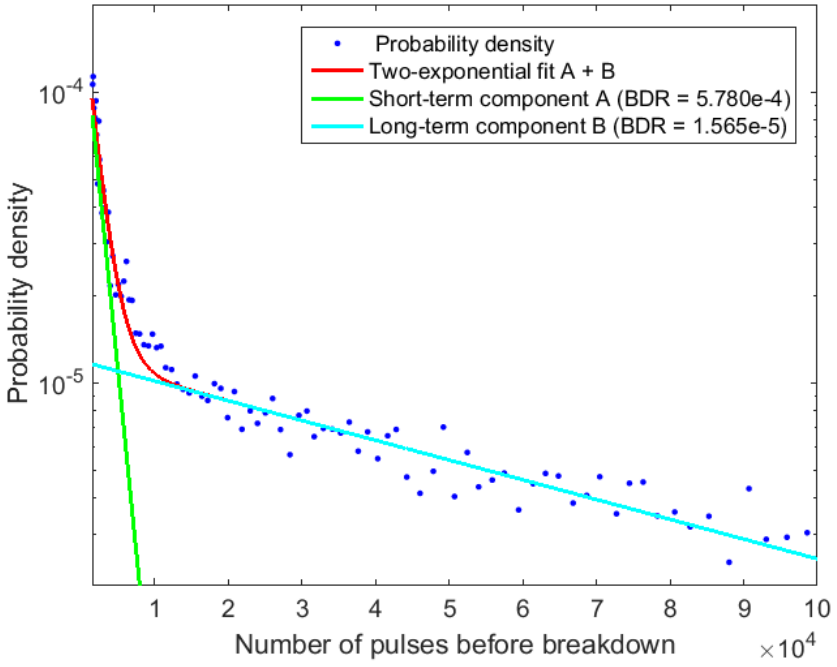
Statistics of nr of pulses to BD

Due to the timeout after having had 100000 consecutive pulses without BD, all values for number of pulses to BD are effectively forced into the range [0 100000].

This gives an opportunity to test the Two-Rate Model under conditions of (roughly) constant BDR, as opposed to constant voltage which it was originally developed for.

Considering that the samples are undergoing drastic microstructural changes during the run, the model fits the data remarkably well!

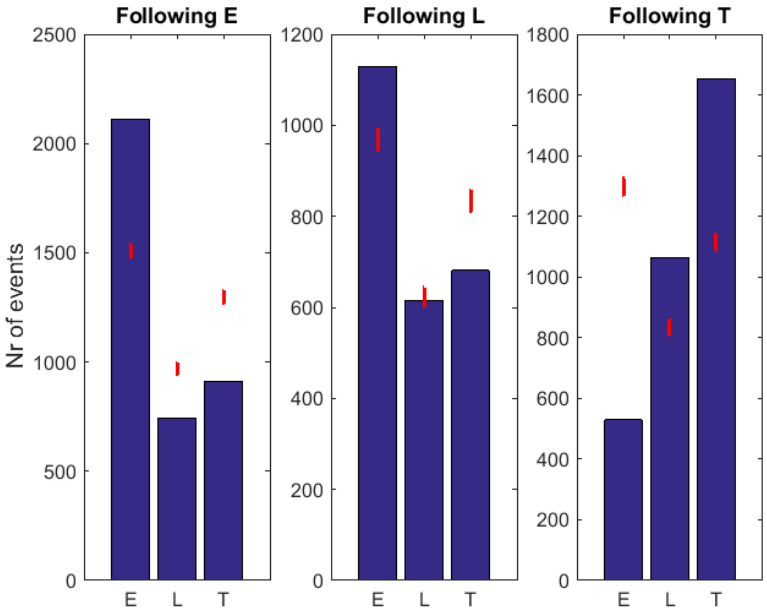
Little discrepancy at very start of distribution; lower bound of fit at 1500 pulses where voltage ramp-up is considered to end. Yet, number of even earlier breakdowns higher than this fit (though should be lower due to lower voltage)



Correlation of iteration outcomes

Each iteration of the algorithm has an outcome which is one of three “events”: (E)arly breakdown, (L)ate breakdown, (T)imeout. The total number of each event were as follows. E: 3772. L: 2425. T: 3247.

Whether events are correlated was checked by calculating the distributions of events immediately following events of each type, and comparing to the expectation value (and error of the mean) for uncorrelated events:

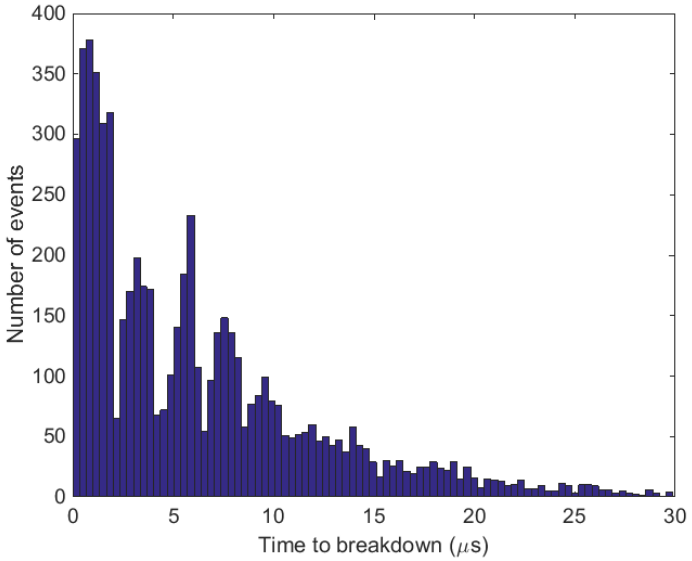


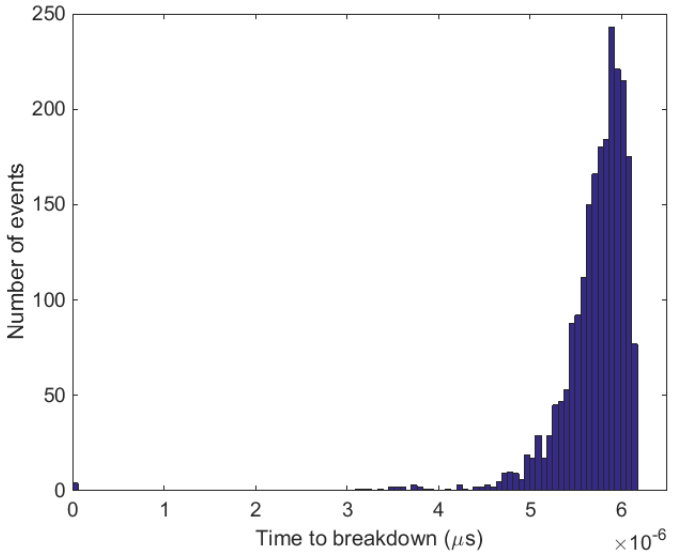
Events are clearly correlated, breakdowns of both types have a higher likelihood of being followed by more breakdowns and timeouts more like to be followed by timeouts, despite the feedback loop acting to the contrary.

This could be short-term fluctuations in conditioning state, but might also be clustering inherent to breakdown dynamics.

Statistics of time to breakdown

For each breakdown, time from start of the pulse to the breakdown was recorded. A histogram of the distribution is shown (left image):





The shape of the distribution is (rather) consistent with both RF and Nick's old measurements, but not with my previous measurements on the Large Electrode System, done with the old electrodes. With them, I would get breakdowns piled up at the end of the pulse, and hardly any during the voltage rolloff after the pulse (right image)

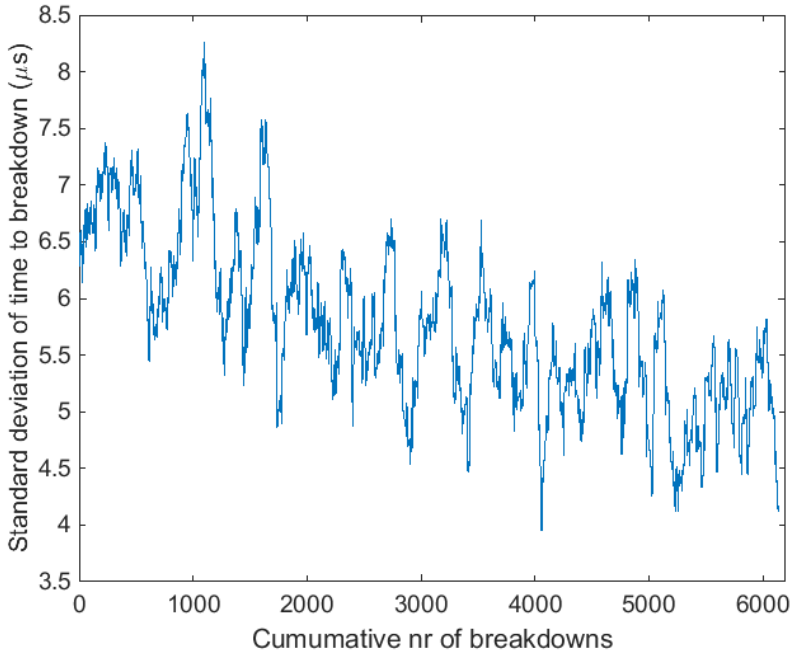
To explain this apparent discrepancy, I present you my hypothesis of structure regularization.

Structure regularization

Hypothesis: Conditioning does not simply make the structure better, it also makes it more homogenous, and thus the micro-processes of breakdown more deterministic, which can e.g. be seen in a decrease in the spread of time to breakdown. This would explain why the old samples behaved differently from every other, they had undergone far more conditioning than any other samples anywhere (DC or RF)

The graph shows how the spread of time to BD evolves, calculating the standard deviation of the times to breakdown of a sliding window of 100 consecutive breakdowns.

We see a slow but steady decrease in spread over the course of the run so far. Thus far the hypothesis holds, it remains to be seen whether it continues to do so.



Conclusions

The experiment has gone well so far.

We have seen an improvement in normalized breakdown rate similar to what we see in RF, validating the use of the Large Electrode System for high rep rate conditioning studies.

We have also obtained some secondary results which we did not expect to, but which might be of scientific value:

-The Two-Rate Model was validated under conditions of constant BDR, even as the electrodes conditioned

-Evolution of spread of time to breakdown over the course of conditioning may give hints to the underlying micromechanics of conditioning, as well as the whole breakdown process