NEW QUANTITY DESCRIBING THE PULSE SHAPE DEPENDENCE OF THE HIGH GRADIENT LIMIT IN SINGLE CELL STANDING-WAVE ACCELERATING STRUCTURES

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Abstract

A new quantity has been developed to study the relationship among the breakdown rate, the pulse width and the gradient. Difference pulse shapes can be treated by introducing a Green's function. This paper describes the quantity and the results while it is applied to the data of many high-power test runs of different single-cell standing wave accelerating structures. A remarkably similar relationship between the new quantity and breakdown rate is observed from all of the test results.

INTRODUCTION

Vacuum rf breakdown is a critical issue which limits normal temperature accelerators achieving higher gradient. It is a complicated phenomenon involving effects which are described in different fields of applied physics such as surface physics, material science, plasma physics, and electromagnetism [1] and the fundamental mechanism is still under study. A new quantity based on pulsed surface heating equation was proposed to study the pulse width and gradient dependencies of the breakdown rate of accelerating structures. Experimental data of several single-cell standing wave structures tested in SLAC was used to check the validation of this quantity. The new quantity gives the high gradient limit of accelerating structures due to breakdown and can be used to guide high gradient rf design.

NEW QUANTITY

RF pulsed heating resulting from a surface magnetic field created from rf pulse is one of the possible limitation to achieving high power in accelerating structures. It is also a parameter used to optimize RF cavity design by suppressing it under a reasonable value. 1D solution of temperature rise by rf pulsed heating reported in [2] is:

$$\Delta T = \frac{1}{\sqrt{\pi \rho c_{\varepsilon} k}} \int_0^t \frac{1}{\sqrt{t-t'}} \frac{dP(t')}{dA} dt' , \qquad (1)$$

where ρ is the density, c_{ε} is the specific heat at constant strain, k is the thermal conductivity, dP/dA is the power dissipated per unit area. Based on equation (1), a new quantity I_{α} is proposed as below:

$$I_{\alpha} = \frac{1}{\sqrt{\pi \rho c_{\varepsilon} k}} \int_0^t (t-t')^{-\alpha} \frac{dP(t')}{dA} dt' . \qquad (2)$$

Here α is a value between zero to one which is still under defined. It can be easily seen that I_{α} equals as pulsed surface heating when $\alpha = 0.5$.

SINGLE-CELL STANDING WAVE STRUCTURE EXPERIMENT

High power tests of single-cell standing wave structures were done to study the basic mechanism of breakdown phenomenon in SLAC. The goal of this study was to determine the maximum gradient possibilities for normal conducting accelerators and explore the limitation for high gradient [3,4]. The single-cell standing wave structure consists of three parts: the input coupler cell, the high-gradient middle cell, and the end cell [5]. The geometry of the middle cell, which are the cells of interest, are based on the geometry of a periodic accelerator structure cell. Fields in the other two cells are designed to be at most one half of the middle cell fields, so breakdowns will likely occur in the middle cell. Five structures with three different geometries whose testing results were studied, analysed and compared to evaluate our new quantity in this paper are shown below:

- One-C-SW-A2.75-T2.0-Cu-SLAC-#1
- One-C-SW-A3.75-T2.6-1WR90-Cu-SLAC-#1
- One-C-SW-A3.75-T2.6-Cu-SLAC-#1
- One-C-SW-A5.65-T4.6-Cu-KEK-#2
- One-C-SW-A5.65-T4.6-Cu-Frascati-#2

More details of these structures are introduced in [3,4].

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EXPERIMENTAL DATA ANALYSIS

Input Power for the Test Structure

As the filling time of single-cell standing wave structure can be as long as 100 ns, a step input power (green line in Fig. 1) is used for the high power test operation to obtain a relatively constant gradient (blue line in Fig. 1). The cyan dash line is the I_α calculated by the waveform of gradient. The maximum of I_α will be used to evaluate the breakdown rate of the single-cell standing wave structures in the next section.

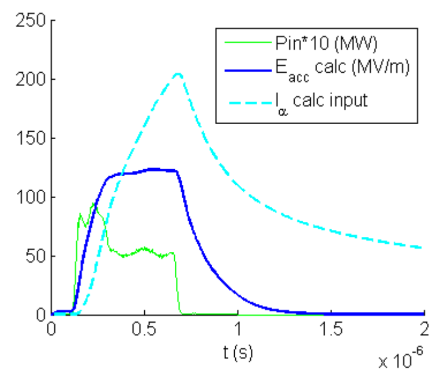

Figure 1: Input power, Eacc and I_α in the structure.

One-C-SW-A2.75-T2.0-Cu-SLAC-#1 Analysis

Firstly we will show the analysis method based on the new quantity for one structure and then the comparison with will be presented in next section. Here the result of One-C-SW-A2.75-T2.0-Cu-SLAC-#1 is used to as an example.

Breakdown rate was evaluated during the high power test of the single-cell standing wave structure. It was measured at a fixed value of gradient and pulse width. The raw data of the breakdown rate evaluations is shown in Fig. 2. Totally 19 times of breakdown rate was measured at four pulse widths and various accelerating gradients. The results of different pulse shape operation diverge from each other and cannot be compared easily.

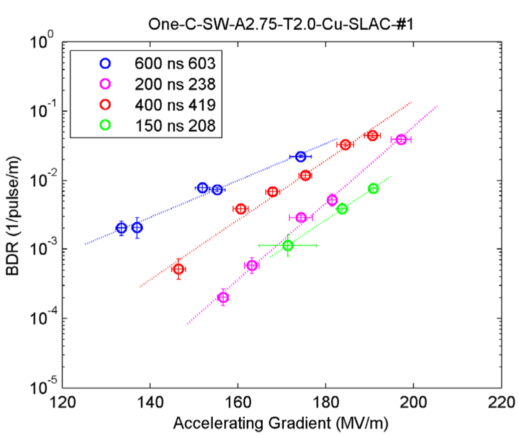

Figure 2: Raw data of One-C-SW-A2.75- 2.0-Cu-SLAC-#1.

Then we replot the breakdown rate dots as the function of maximum of I_α by applying different α from 0.3 to 0.7. The results whose α is 0.4, 0.5 and 0.6 are shown on Figs. 3 - 5. It can be found that breakdown rate has strong dependency on I_α when taking all the pulse width and gradient operation into account and comes to a similar linear relationship with I_α in the semi-logarithmic coordinate system.

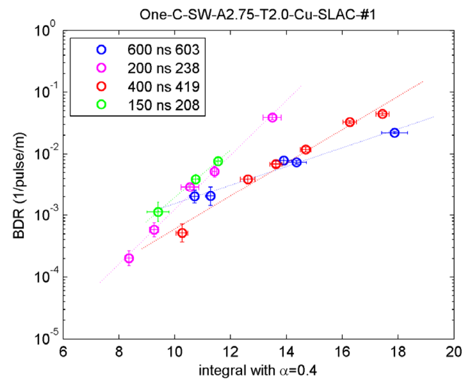

Figure 3: Breakdown rate vs $\max(I_\alpha)$ (α=0.4).

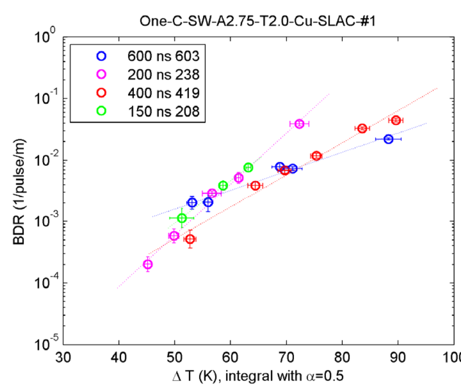

Figure 4: Breakdown rate vs pulsed surface heating.

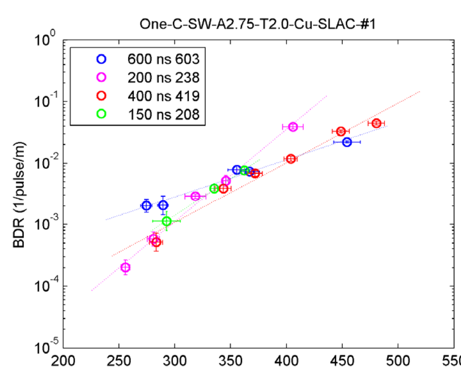

Figure 5: Breakdown rate vs $\max(I_\alpha)$ (α=0.6).

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The correlation between $\max(I_\alpha)$ and breakdown rate is defined as below:

$$corr = \frac{\mathrm{cov}(BDR, \max(I_\alpha))}{\sigma BDR \cdot \sigma \max(I_\alpha)}, \qquad (3)$$

where cov means covariance and σ is the standard deviation. This value can be used to describe the breakdown dependency on $\max(I_\alpha)$. The correlation result for different α is shown in Fig. 6. It indicates that breakdown rate has strongest dependency on $\max(I_{0.6})$ for One-C-SW-A2.75-T2.0-Cu-SLAC-#1.

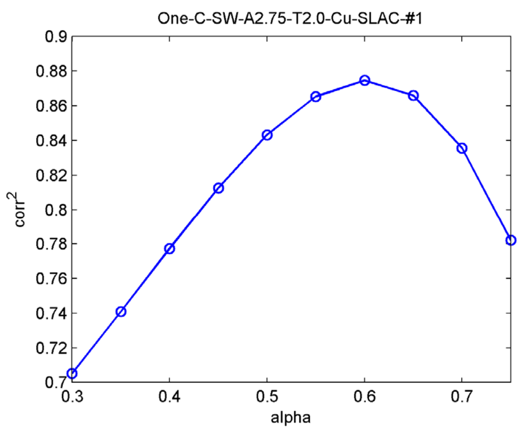

Figure 6: Correlation vs alpha.

Comparison With Other Structures

Similar analysis was done for the other four structures and summary of the results is shown in Fig. 7. We can find highest correlation between $\max(I_\alpha)$ and breakdown rate is achieved when α is from 0.5 to 0.7 for all of the five structures. The breakdown rate shows strong dependency on the new quantity I_α for the experimental data by applying a proper α. I_α represents the high gradient limit and provides a way of comprehensively analyzing and comparing the data of various structures measured at different pulse shapes.

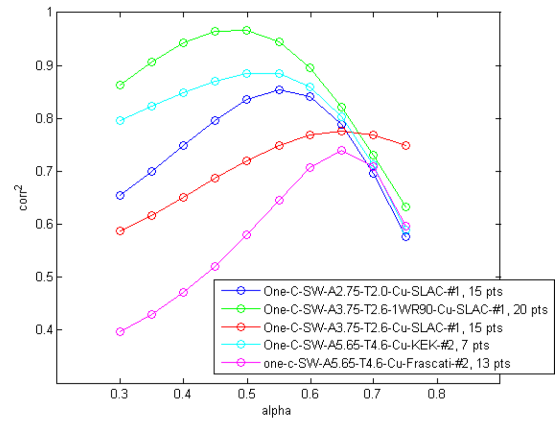

Figure 7: Summary of correlation calculation for all of the five structures

CONCLUSION

The breakdown rate shows strong dependency on the new quantity I_α from the test results of single-cell standing wave structures. Breakdown rate measured at difference pulse shapes can be normalized and compared together by introducing I_α. The new quantity I_α which indicates the high gradient limits provides a way of comprehensively analyzing and comparing the data of various structures measured at different pulse shapes and serves as a guidance in the design of high gradient structures.

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