

DAMAGE REDUCTION IN ELECTROSTATIC SEPTUM ARCS

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With proper resistors in the external high voltage circuits associated with an electrostatic septum, the energy dissipated in a fault arc can be limited to that electrostatically stored in the septum geometry. However, this stored energy in many designs is still a large enough cause for concern. In wire septa it may be sufficient to burn wires and in foil septa it may be sufficient to spoil the carefully prepared surfaces. The first approach to this problem is to subdivide the septum and resistor - isolate these subdivisions limiting the energy flowing into a fault to that stored in only one subdivision. It is difficult to carry this approach beyond a few subdivisions because of mechanical problems.

An alternate solution may be to divert a large fraction of the stored energy to a dissipater by proper coupling to the electromagnetic fields associated with the fault.

The parameters of the presently planned BNL electrostatic (HTS) septum will be used to illustrate this approach. The approximate dimensions are:

length	254 cm
height	7.1 cm
gap	1 cm

This geometry forms a transmission line with a characteristic impedance given by

$$Z_o = 377 \frac{\omega}{\ell} = 53 \text{ ohms}$$

If this system is charged to a potential V and a fault occurs, the instantaneous fault current will be limited by the characteristic impedance, and if the arc impedance is ignored, this current is given by

$$I = \frac{V}{Z_o/2} = 3770 \text{ amps}$$

where V = 100 kV

Note - current is supplied from both sides of the fault.

This initiates two electromagnetic waves which travel down the transmission line and are reflected by the open circuited ends. When they return to the point of the fault, the current will reverse. If the fault is in the center of the septum, a simple full current reversal will occur. The current in the fault, as a function of time, will be a square wave decaying with time depending on the Q of the fault system. If the fault is not in the center of the septum, the fault current waveform will be a heterodyne between two square waves of different frequency which will also decay with time.

The Q of the fault system is effected by many parameters, such as eddy current and radiation losses as well as the ohmic resistance of the fault arc itself. By design it may be possible to divert energy flow away from the fault arc into one of the other dissipaters.

If the ohmic resistance of the fault arc is the predominant dissipative element, most of the stored energy will ultimately be dissipated in the arc and manifest itself as arc damage. Other loss mechanisms will lower the total Q of the septum and shorten the decay time constant of the fault current. This will result in less energy being dissipated in the arc and therefore less arc damage.

The fault current decay time constant with arc loss can only be estimated.

$$\lambda(\text{time constant}) = Q/\pi \text{ cycles} = Q/\pi f \text{ seconds.}$$

$$Q = \frac{\text{energy stored}}{\text{energy dissipated per radian}} = \frac{J}{I^2 r / \omega}$$

where r = arc resistance

I = fault arc current at time zero

ω = angular frequency

J = initial stored energy.

Initial measurement by M. Fruitman indicates that r is of the order of 2/3 ohms. (It should be noted with caution that this measurement was made at a much lower frequency than the frequency of this example.)

$$\omega = 2\pi f = \frac{2\pi}{\text{Period}} = \frac{2\pi c}{\ell}$$

where c = velocity of light

ℓ = length of septum

therefore

$$\omega = 742 \times 10^6 \text{ rad/sec (} f = 118 \text{ MHz)}$$

$$J = \frac{1}{2} c V^2$$

where $V = 100 \text{ kV}$

$c = 200 \text{ pf (estimated)}$

therefore $J = 1 \text{ joule}$

$$Q = 78.3$$

$$\lambda = 211 \text{ nanoseconds}$$

To appreciably reduce the fault arc damage, the Q of the total system must be reduced below the 78 computed above. There are many ways to couple electromagnetically to introduce loss to this system. Reduction of Q below 10 should be possible. A set of broadly tuned conducting loops magnetically coupled to the region of stored energy with resistors attached appears to be one such method. Slots in the ground potential surfaces, electrically resistive material and electrostatically coupled loads represent other approaches. Modeling and Q measurements should determine the optimum approach.

In order to better understand the potential of this approach, a study of the time rate of growth of damage in tungsten was undertaken with the aid of a computer and a simple model.

The model involves the following simplifications:

1. The arc is a line of current striking an infinite plane of tungsten.
2. The resulting hole or dimple is spherical in shape.
3. As the hole grows in radius, the current continues to enter the tungsten uniformly distributed over the surface of the hole.

4. The energy of incoming ion is neglected, only ohmic heat is considered.

5. Radiation loss is included, but only from the hole surface.

6. A linear temperature coefficient of resistivity is assumed.

7. Coefficients of thermal conduction, specific heat, specific gravity are assumed to be constant.

8. Boiling tungsten is removed.

9. Basic constants are:

Boiling Temperature	5927°C
Volume Resistivity	5.6×10^{-6} ohm cm
Temperature Coef. of Resistivity	0.0045 per °C
Specific Gravity	19.35
Specific Heat	0.0322
Thermal Conduction Coef.	1.6 watts/cm °C
Stefan-Boltzmann Constant	5.67×10^{-12} watts/cm ² °K ⁴

The results of these calculations are summarized in Figs. 1 and 2.

Figure 1 shows dimple-size as a function of time for nondecaying input current of two values. Figure 2 shows final dimple-size as a function of current decay time constant. Radii are measured in microns (0.001 inches equals 25.4 microns).

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