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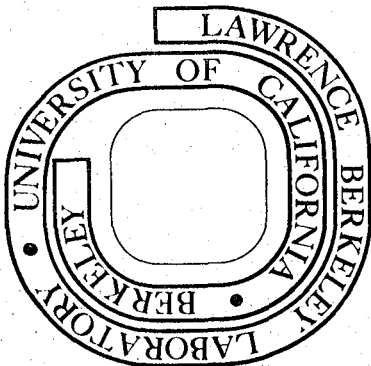
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January 1979

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## ARC SNUBBERS FOR NEUTRAL BEAM SOURCES

At LBL it has been observed and verified many times that the amount of  $1/2 CV^2$  energy associated with the accel grid that a neutral beam source can tolerate under sparkdown conditions is quite limited. If this energy exceeds approximately 5 - 7 Joules, serious degradation of the voltage holding capability of the source occurs. To allow a margin of safety, a 3 Joule maximum has been set as a design goal.<sup>1</sup>

It is perhaps relevant to note here that this limitation does not occur in the case of high vacuum modulator tubes where 50 Joules is acceptable and even beneficial.<sup>2</sup> The difference is apparently associated with the few microns of gas present in neutral beam sources. This provides a much faster space charge neutralization capability in the accel gap so that a high current discharge can develop in a few nanoseconds. In a vacuum tube where the neutralizing ions must come from the electrodes, the time is much longer. A study of the latter type of breakdown was made for a switch-tube project at LLL, where this was found to be 1 - 2  $\mu$ secs.<sup>2</sup> In a source, the discharge can be much more localized because of the gas and, in fact, may become a "pinch" type discharge where the magnetic field of the arc column focuses the discharge into a small channel.

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1. UCID 8069
  2. UCID 15524

It has been observed that there are both "slow" and "fast" types of discharges in LBL sources. The "fast" mode generally occurs above 25 kV with the present molybdenum electrode structures and a critical value of capacitance. For the earlier copper grids, it was somewhat lower. When more capacitance than this is present, the "fast" mode is observed to take place at approximately 400 amps over and above the normal accel current. Below this level, a "soft" mode dominates that apparently causes little or no degradation of voltage holding with as much as 60,000 pF across the source.

When the LBL 10 x 40 cm source was upgraded from 20 to 40 kV, even the lowest capacitance power supplies that we could devise were only marginally acceptable. Some voltage holding difficulty occurred at the higher voltages as expected.

Fortunately, a possible solution for this problem had been devised shortly after it was first observed. The idea was to use a stack of transformer cores near the source and route all of the power supply leads through them. In effect, this "core stack snubber" serves as a one-turn transformer that transiently separates the energy in the capacitances of the power supplies from the source and allows a limited current RC discharge of this energy rather than the normal high current LC oscillatory type. By proper design, the core itself supplies the desired transient series resistance as well as the necessary volt seconds. Several such snubbers are being used on the various LBL test stands. The device is apparently essential to the operation of the present sources at 120 kV.

The following is given as an example of how such a snubber is designed. It is for the NBSTF\* and has been built and tested at the full expected operating voltage level. The observed current limiting and capacitor discharge characteristics were essentially as the calculations had indicated.

\*Neutral Beam Source Test Facility constructed in the 184" Cyclotron Building 6 at Lawrence Berkeley Laboratory for the long pulse testing of sources at the 10 megawatt, 150kV level for the Princeton Tokamak Fusion Test Reactor.



The recent dismantling of the Astron accelerator made available at no cost a large number of toroidal transformer cores suitable for arc snubber use. These are 8 3/4 in. i.d. x 24 in. o.d. and are wound with 1/2 inch wide x .0005 inch 50-50 nickel-iron material. The pulse electrical characteristics are covered in an article by Winter, Kuenning and Berg in IEEE Transactions on Magnetics, Vol. 6, #1, p.41, (1970).

The active cross-sectional area of one of these cores = .5 inch x 7.625 inch x (2.54)<sup>2</sup> x .7 estimated packing factor = 17.22 cm<sup>2</sup>. This is 3.13 times the active area of one of the 60 10 inch cores used in the snubber on the LBL 120 kV TS III B facility, so 20 of these would give approximately the same volt seconds. However, since space was available for a 40-core assembly and the extra volt seconds and series transient resistance could be useful later for higher voltage source operation, it was decided to use the 40 cores.

$$\frac{7.625'' \text{ radial core width}}{.0005'' \text{ lamination thickness}} \times .7 \text{ packing factor} =$$

$$10,675 \text{ laminations/Astron core}$$

$$40 \text{ cores} = 427,000 \text{ laminations}$$

$$V/\text{lam.} = \frac{120,000}{427,000} = .281$$

$$V/\text{cm around each lam.} = \frac{.281}{2.54} = .111$$

$$H = 5.65 E^{1/2} = 5.65 \sqrt{.111} = 1.88 \text{ Oersteds (re above reference)}$$

Current to drive the snubber core laminations =  $1.88 \times \pi 16.4''$  average core diameter  $\times 2$  A/in./Oe = 194 A.<sup>3</sup>

$$R/\text{lam.} = \frac{V/\text{lam.}}{194} = \frac{.281}{194} = .00145 \Omega$$

$$R/\text{snubber} = .00145 \times 427,000 \text{ lam.} = 618 \Omega$$

NBSTF RC discharge time =  $618 \Omega \times 2 \times 10^{-9}$  F. estimated system capacitance =  $\sim 1.3 \mu\text{sec.}$  Volt seconds for 40 cores, assuming full back bias =  $2.8 \times 10^4$  lines/cm<sup>2</sup>  $\times 40 \times 17.22 \text{ cm}^2 \times 10^{-8} = .192$ . The core time available @ 120 kV operation and an RC type discharge of this type<sup>4</sup> =

$$\frac{.192}{1.2 \times 10^5 \times .5} = 3.2 \times 10^{-6} \text{ sec.}$$

$$C \text{ allowed} = \frac{3.2 \times 10^{-6}}{618} = >5000 \text{ pF}$$

The required H to back-bias these cores is  $\sim 0.1$  Oe. This is  $2$  A/in./Oe  $\times \pi 24$  in. = 15 A bias current at the core periphery. Because this bias current appears as an additional current to the source when sparkdown occurs, it should be kept as low as practical.

The bias current return is outside the snubber. Hence, this return lead requires a series inductance of a few mH so that no significant additional current can reach the source when sparkdown occurs and the

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3. For a long solenoid,  $H = \frac{.4\pi nI}{2.54}$

Units are oersteds, turns per inch and amps.

4. Note: Because the snubber resistance is proportional to  $\sqrt{V}$ , the "RC" discharge is essentially linear instead of exponential. Hence, the average voltage that the snubber sees is .5 and the discharge is essentially complete in a single RC time.

accel voltage transient appears across the snubber and this inductance. It has been the practice on our several operating test stands to make this inductor a single layer solenoid with the core stack inside this. The individual cores are spaced apart with low dielectric washers to keep the overall distributed capacity low. Measurements indicate that the pulse inductance is essentially the same with or without the cores present. The system capacitance to ground, however, is less than with two separate systems because the electric fields are mutual. The solenoid field due to the bias current is less than 100 Gauss for the design given below. This does not interfere with the normal transformer operation because the fluxes of the two systems are at right angles to each other. The bias current is provided by the source filament supply and the operating level is set by the proper solenoid resistance plus a small adjustable separate series R. Because the source fil. comes on approximately 2 seconds before the accel, it is not necessary to provide more bias current than the maximum operating accel current.

The coil design selected for the bias current return limits the accel current increase at sparkdown to approximately 10 A and provides the required core back bias.

36 inch o.d. x 36 inch long solenoid

120 turns evenly distributed 1/4 inch x 1/4 inch copper conductor

L of coil = 7.7 mH

R of coil = .122  $\Omega$

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