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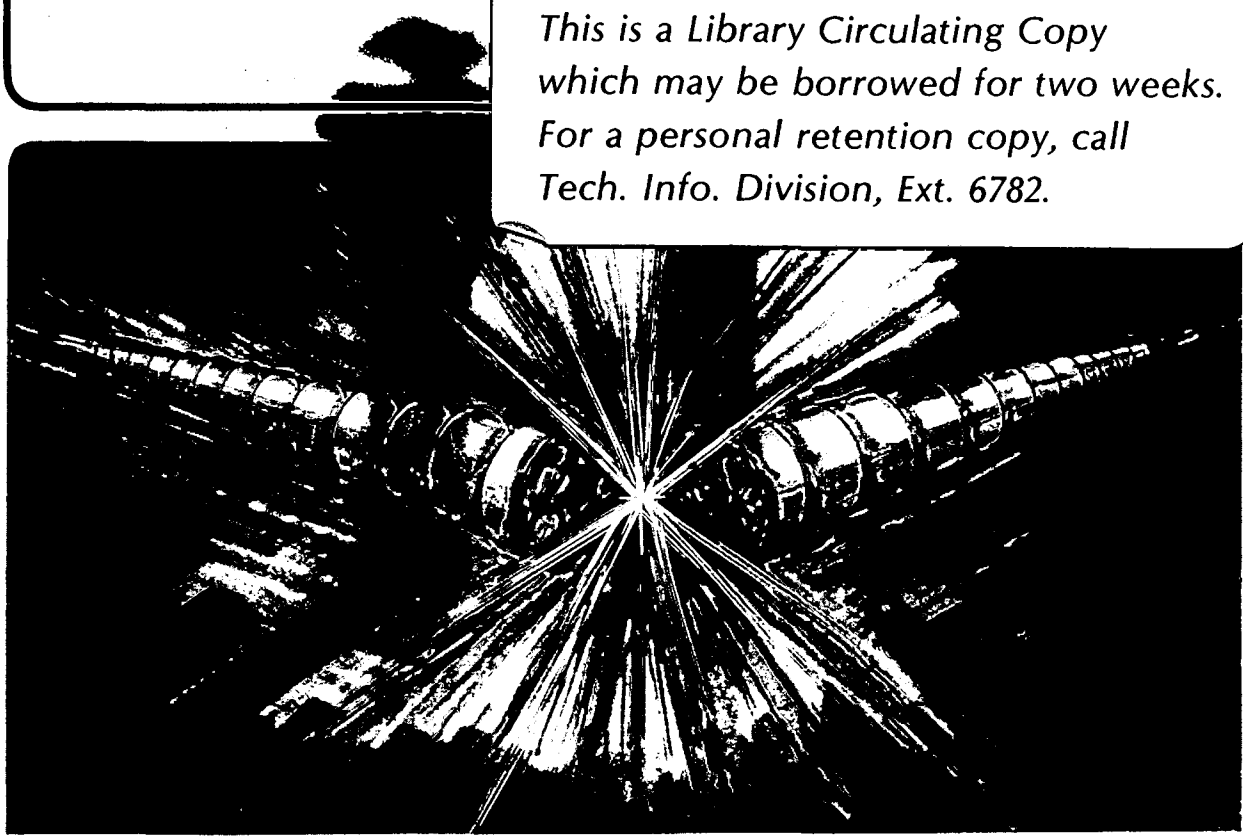

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THE EFFECT OF CAPACITIVE STORED ENERGY ON NEUTRAL BEAM ACCELERATOR PERFORMANCE*

H.M. Owren, W.R. Baker, K.H. Berkner,
D.B. Hopkins & D.J. Massoletti

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720 USA

ABSTRACT

The results of tests to determine the effects of capacitive stored energy ($1/2\ CV^2$) on the performance of neutral beam injectors are reported. Typical fault current waveforms and methods to limit fault current are presented. Tests indicate that deterioration of performance is not only a function of peak stored energy but is also dependent on peak current and the characteristics of the breakdown.

1. INTRODUCTION

Ion sources for the production of neutral beams consist of an ion chamber and an accelerator electrode structure. A high voltage is applied to the electrodes to accelerate the ionized atoms into the neutralizer and other beam line components. Voltage gradients in present structures are in the order of 100 kV/cm. The total applied voltages are as high as 120 kV with ion currents of 65 A. Under these conditions, voltage breakdowns frequently occur. These "spark downs" only occur in the presence of an ion current and a period of conditioning is required before the systems will operate reliably at the rated voltage and current. This conditioning process consists of operating the system at reduced voltage and current, and gradually increasing both as the system "cleans up".

To prevent damage to the electrodes, the power supplies are designed to limit the fault current and switch off in a few microseconds when a "spark down" is detected and, after a predetermined time interval, switch on again. Although this switching removes the power supply from the fault circuit, there is energy stored in the inductance and capacitance of the electrical circuit between the switch and the source. This energy is dissipated in the circuit elements, including the interelectrode arc. In typical systems, this stored energy ranges from a few Joules to 20 or more. As the systems become larger and operate at higher voltages, the amount of energy stored in the capacitance to ground ($CV^2/2$) may limit the performance of these systems. This report summarizes the results of a number of tests performed at LBL to determine the effect of this stored energy on system performance.

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2. DESCRIPTION OF TEST SYSTEM

The major components of a neutral beam system are shown in Figure 1 and their functions are as follows.

The ion chamber, and the filament-arc power supplies are connected to the positive terminal of the accel supply. On a four grid structure, the potential of the second electrode is 80 to 90% of the accel potential. On a three grid structure, this electrode is omitted. The function of the third electrode is to suppress electrons (suppressor) and is maintained at a negative potential. The fourth electrode is held at ground potential and the accelerated ion beam exits here into the neutralizer and other beam line components.

Cs represents the stray system capacitance to ground. Cm is a monitor capacitor and its current is monitored by current transformer CT-1. This capacitor is in parallel with the stray capacitance Cs; however, because of the distribution of the circuit capacitance and inductance, the current in Cm is not proportional to the ratio of Cm to (Cm + Cs). We calibrated this monitor by measuring the current through a spark gap switch connected from source to ground. Although the amplitude was not proportional to the capacitance ratio, the wave shapes of the monitor currents and spark gap currents were similar.

C_{TEST} represents the various amounts of capacitance connected from source to ground to establish the stored energy limit on performance. For some tests, resistance and/or inductance was connected in series with C_{TEST} to determine the effect of limiting the peak

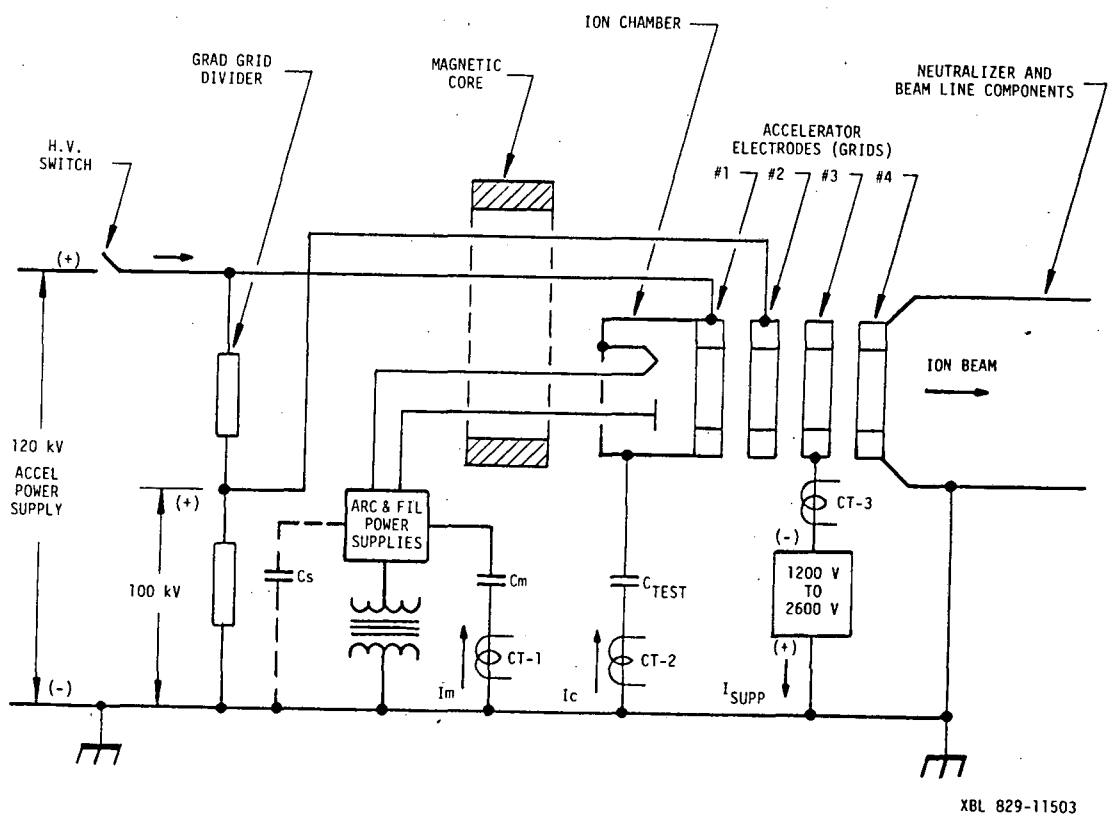

Fig. 1 Schematic diagram of neutral beam power system

current. CT-2 monitors the current in this part of the circuit during a "spark down". CT-3 measured the "spark down" current in the #3 electrode (suppressor). The component labeled "magnetic core" acts as a series resistance to limit "spark down" current from that capacitance which is on the power supply side of the core.[1,2]

3. TEST PROCEDURE

The first test were conducted using a LBL three grid, 40 kV, 50 A accelerator. All other tests were conducted on four grid accelerators designed for either 80 kV or 120 kV operation. The test procedure was as follows.

The system was first conditioned at some specified operating voltage. Varying numbers of additional capacitors were then connected from the high voltage accelerator electrode to ground (see fig. 1). When a "spark down" occurred, the additional energy stored in this capacitance was discharged into the fault. It was necessary at times to raise the operating voltage to force a "spark down". The voltage was then lowered and held constant for the duration of the test. Performance was determined by monitoring the number of interrupts per pulse or the total on-time. If the average percentage on-time became less with the extra capacitance or if we found the conditioning process had definitely slowed, we considered this a degrading of performance. It does not mean that any permanent damage had occurred to the structure. Tests were also conducted to determine the effect of limiting "spark down" current by connecting resistance or inductance in series with the added capacitance. Current transformers were used to measure the currents in the various circuit elements.

4. TEST RESULTS

4.1 With a 80 kV four grid accelerator, the undamped peak currents in a "spark down" varied from approximately 400 A to 3000 A.

4.2 Degrading of performance did not occur unless "spark downs" gave peak currents above approximately 600 A, giving rise to the terminology of "soft sparks" and "hard sparks". It was necessary at times to raise the operating voltage to force a "hard spark" before any effect of the added capacitors could be noted.

4.3 Degrading of performance occurred when the undamped stored energy was greater than 5 or 10 Joules <u>and</u> the peak current exceeded 600 A.

4.4 If the peak currents were limited with series inductance and/or resistance, operation with up to 40 Joules has been possible. The exact limit of stored energy vs peak current has not been determined.

4.5 Tests on a 40 kV, 50 A, three grid accelerator were conducted at 37.5 kV accel. We were able to monitor the total fault current to the accelerator in this system. The peak currents varied between 300 and 1400 A. After installing a magnetic-core current-limiting device in the circuit, we found the operation at 40 kV greatly improved.

4.6 Examination of the current wave forms from CT-1 and CT-3 (suppressor) indicated that in a four grid structure the majority of the breakdowns terminated on this electrode (fig. 2). Some breakdowns do occur with only very small currents showing on this electrode. We did not measure the suppressor spark down currents on a three grid device. These measurements were made without any added capacitance and with the magnetic-core current-limiting device in the circuit.

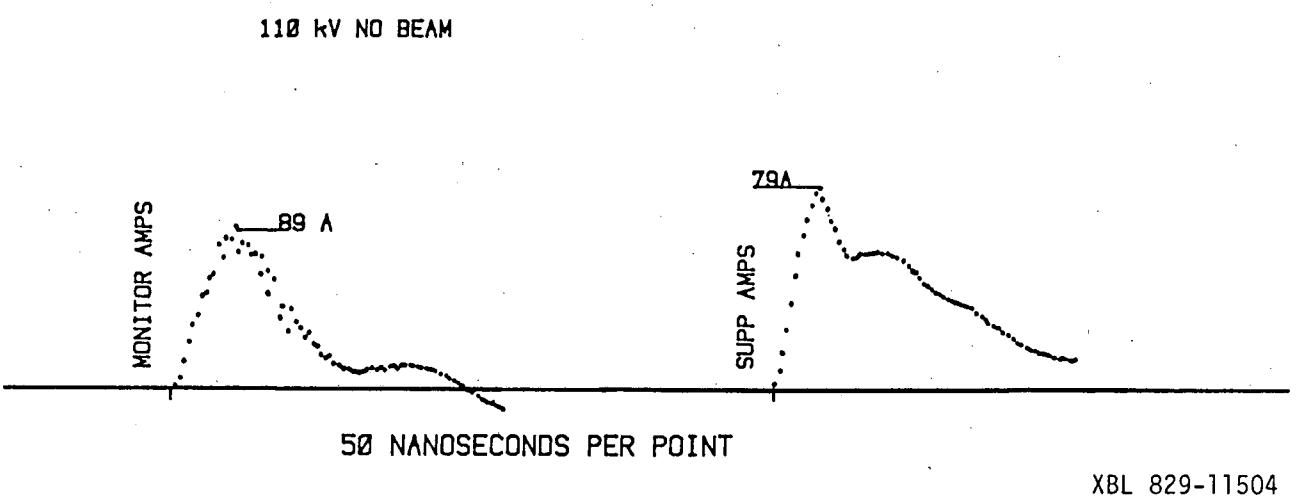

Fig. 2 Monitor and suppressor current waveforms

4.7 Fig. 3 is a histogram of percent of requested pulse on-time vs the number of shots. In this case, the accelerator was conditioned at 80 kV and it was necessary to raise the voltage to 87 kV to create a hard spark. After the spark, the accelerator performance had definitely deteriorated. C_{TEST} was then removed to observe the cleanup history.

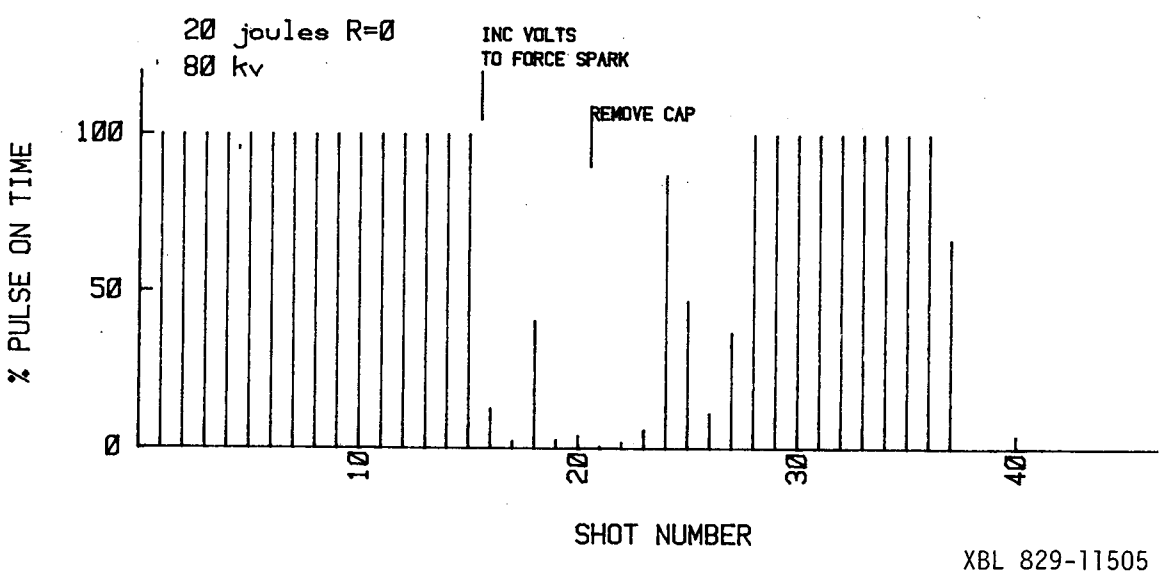

Fig. 3 Histogram of pulse on-time after hard spark

Fig. 4 shows the cleanup after a hard spark under the same conditions as fig. 3 except 200 ohms of resistance was connected in series with C_{TEST}.

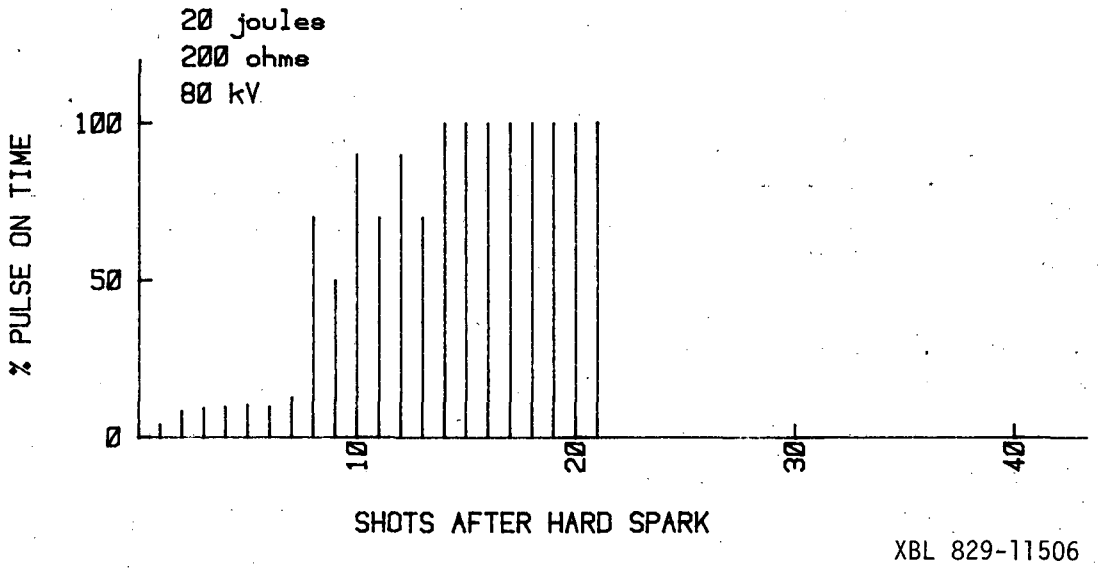

Fig. 4 Histogram of percent on-time after hard spark with 20 Joules and series R (200 Ohms)

Fig. 5 shows the cleanup under the conditions of fig. 3 except 100 x 10^{-6} H of inductance was connected in series with C_{TEST}.

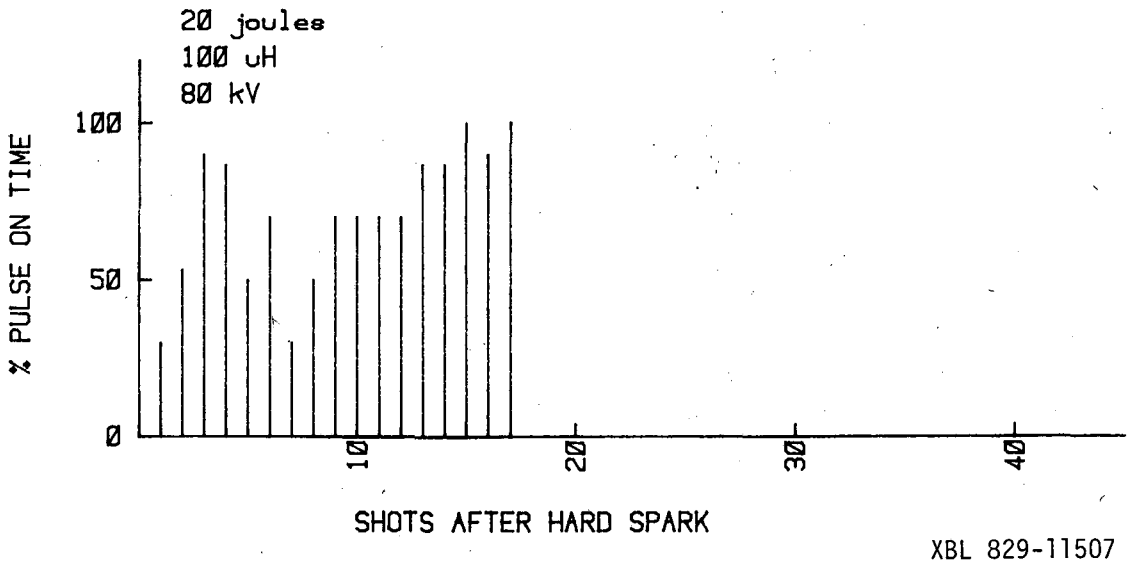

Fig. 5 Histogram of percent on-time after hard spark with 20 Joules and series L (100 x 10^{-6} H)

These results are shown to illustrate the method used to determine "deterioration of performance".

5. CONCLUSION

Because the tests on the 40 kV, 50 A accelerator indicated that currents in excess of 600 A affected performance, all of the neutral beam systems at LBL have had a magnetic-core current-limiter in the circuit. These limiters have been designed to limit the peak "spark down" currents to 300 A. Under these conditions, we have obtained successful operation of accelerators at 120 kV accel voltage and pulse lengths of many seconds. Present facilities limit the pulse length of the 65 and 80 A accelerators to a few seconds but new facilities under construction will permit operation at 120 kV, 65 A for 30 seconds at 10% duty factor. The tests indicate that for reliable operation it is desirable to include in the electrical circuit methods to limit the peak "spark down" currents to a few hundred amperes and to minimize the capacitance stored energy ($CV^2/2$).

6. REFERENCES

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