Title

FLAT-TOPPING MAGNET CURRENT FOR THE BERKELEY ELECTRON-RING-ACCELERATOR EXPERIMENT

Permalink

https://escholarship.org/uc/item/84h8p9j8

Authors

Baker, William R.
Gagnon, William L.
Voelker, Ferdinand.

Publication Date

1969-02-10

UCRL-18749
cy. 2

FLAT-TOPPING MAGNET CURRENT FOR THE BERKELEY ELECTRON-RING-ACCELERATOR EXPERIMENT

William R. Baker, William L. Gagnon,
and Ferdinand Voelker

February 10, 1969

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

UCRL-18749
cy. 2

Presented at the National Particle Accelerator
Conference, Washington, D. C., March 1969

UCRL-18749

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

FLAT-TOPPING MAGNET CURRENT FOR THE BERKELEY ELECTRON-RING-ACCELERATOR EXPERIMENT

William R. Baker, William L. Gagnon, and Ferdinand Voelker

February 10, 1969

FLAT-TOPPING MAGNET CURRENT FOR THE BERKELEY ELECTRON-RING-ACCELERATOR EXPERIMENT*

William R. Baker, William L. Gagnon, and Ferdinand Voelker
Lawrence Radiation Laboratory
University of California
Berkeley, California

A device is described for "flat-topping" or stopping the decay of current in a crowbarred magnet.

Introduction

The Berkeley electron-ring-accelerator experiment requires generation of several time-sequenced magnetic fields to compress an injected electron ring from a radius of 25 cm to a radius of 3.8 cm. It was necessary to hold the electron ring at 3.8 cm radius for several milliseconds in order to study radiation and gas ionization effects in the compressed ring. This was done by flat-topping the current in a short-time constant magnet to within 3% for 3.0 ms. The magnet current was pulsed to a maximum value of 27 kA by a capacitor bank and series switch. A solid-state diode clamped the current at this time, and the current then began to decay at a rate determined by circuit losses. The "flat-top" circuit added enough energy to compensate for the average I^2R losses. This was accomplished by sequentially discharging capacitors into a transformer, the secondary of which was connected to the 27-kA magnet circuit through a separate solid-state diode bridge.

Circuit Considerations

Since it is difficult to store and switch energy at the low impedance level of the crowbarred coil circuit (160 V, 27 kA), we chose to transform to the impedance level of commercially available hydrogen thyratrons and energy-storage capacitors. A transformer with enough iron to supply voltage for the full 3-ms flat-top period is unreasonably large, so it was decided to alternate the polarity of the capacitors which are sequentially discharged into the transformer primary. A diode bridge connects the transformer and magnet circuit as shown in Fig. 1. In this way we can use the full B-H loop without saturating the iron. This also makes it possible to extend the flat-top period to 5 ms or longer by adding more capacitors and thyratrons.

A 42/1 turns ratio yields a primary voltage of 18 kV and a primary current of 650 A at full load. The transformer (shown in Fig. 2) which we built is a low-leakage-inductance design in which the coaxial case acts as the secondary one-turn winding. Two uncut toroidal 4-mil iron cores were wound with a 42-turn primary and insulated with mineral oil. The transformer is about 2 ft in diameter and 2 ft high.

The secondary terminals are coaxial copper plates which constitute the top of the transformer. They are arranged so that an array of copper plates can be bolted to the top of the transformer to continue the coaxial geometry. Between the plates are mounted 960 GE A44M and A45M general-purpose diodes in parallel to make a full-wave bridge. The ends of these diode plates are fastened to a copper coaxial line which passes down through the center of the transformer and which ultimately connects to the magnet. On top of the diode bridge plates is an array of Motorola 1-kA diodes which acts as a diode clamp to crowbar the magnet. Power is brought from the capacitor banks by paralleled RG/8U cables.

The diode bridge acts as the switch to connect the transformer secondary in series with the magnet circuit. The diodes have an average current rating of 20A, a 1-cycle forward surge rating of 300 A, and a peak-inverse-voltage (PIV) rating of 600V. We operate them in pulsed service for 3 ms once a second at between 100 and 150 A, so that the 240 parallel diodes in one leg share the 27-kA load current. The diodes can be paralleled in this service because they are operated above the critical point in the temperature characteristics, at which the voltage drop increases with temperture of the diode.

The charge storage in the diode presented some difficulty. Before each thyratron is fired, the current in each of the legs of the diode gate is equal to half the crowbarred current, and because of symmetry of the bridge, the secondary of the transformer is disconnected from the magnet circuit. When the thyratron is fired, current builds up in the transformer secondary at a rate determined by the energy-storage capacitance and the leakage inductance of the transformer. Current builds up until it equals the current in the crowbarred magnet, at which time two of the diodes should stop conducting and the transformer secondary should be in series with the coil circuit.

---

*Work done under the auspices of the U. S. Atomic Energy Commission.

In practice the diodes continue to conduct in the reverse direction for a short time, and the transformer secondary current continues to rise. When the diodes snap off (in about 1 μs) the sudden decrease of current (back to the magnet current value) in the transformer leakage inductance produces a voltage kick about three times the voltage delivered to the circuit. If this transient exceeds the PIV rating of any diode, the diode tries to carry all 27 kA and literally explodes.

These transients were reduced by paralleled RC damping networks across the transformer secondary. Space limitations required us to settle for a transient of about 1.3 times the delivered voltage, which limited us to a maximum of about 19 kV on the transformer primary.

Charge is removed from the storage capacitor at a constant current (the transformed coil current), and the voltage on the capacitor decreases at a linear rate. When the capacitor falls almost to zero, the blocked diodes in the diode bridge once more carry current, and the transformer secondary is disconnected from the crowbarred coil circuit until the next thyratron is fired.

The deionization time of the thyratrons should be short, because this represents a dead time during which the coil current is decreasing. Most of our difficulties in the high-voltage circuit were due to misfiring of thyratrons. There were eight thyratrons, of which only two should be on at a time. The misfiring was caused when the anode voltage of the off ground-end thyratron was pulsed up. The combination of the interelectrode capacitances and the grid pulse-transformer impedance produced sufficient voltage on the grid to misfire the thyratron. This was corrected by lowering the grid-circuit impedance and adding negative grid bias. Misfiring of the ground-end thyratron caused the energy-storage capacitors to dump energy into the offending thyratron, thus damaging it. An inductance made of a few turns of No. 8 wire in series with the storage capacitors reduced the peak current to prevent damage to a thyratron during a misfire.

Another problem associated with misfires was that the transformer core was uncut and was biased in the reverse direction by the previous pulse. Two successive pulses of the same polarity on the transformer primary caused the core to saturate before the storage capacitor ran out of charge, resulting in an alarmingly high primary current and a short pulse.

These difficulties were cured in the debugging stage, but they emphasize the extra care necessary to eliminate coupling between the firing circuits where a number of thyratrons are operating in the same cubicle.

Design Considerations

An equivalent circuit for the "flat-topping" device is shown in Fig. 3 as a C connected to an LR by an ideal transformer and bridge. At $t = 0$, there is an initial current I_0 in the crowbarred magnet, and an initial voltage V_p on the capacitor. The current in the secondary at a later time is

$$i(t) = e^{-\alpha t}\left[I_0 \cos\beta t + \left(\frac{V_p}{\beta L N} - I_0 \frac{\alpha}{\beta}\right)\sin\beta t\right],$$

where $\alpha = R/2L$, $B = \left[(1/LC_pN^2)-\alpha^2\right]^{1/2}$, and I_0 and V_p are initial values. The resistance R comprises all losses, including lead drop and diode drop. Energy will be delivered from the capacitor for $T = C_pV_pN/I_0$ sec, at which time the capacitor voltage has fallen to zero. There is the additional complication of $i(t) = i(T)\ e(-R/L)t$ for $T < t < T + T_D$, where T_D is the deionization time of the thyratron. The cycle is then repeated.

The problem reduces to finding values of C_p, V_p which make $i(T + T_p) = I_0$, and which also keeps

$$\frac{i_{max}}{I_0} \leq F.$$

Since we are trying to keep the current within ±3% during the flat top, F is equal to 1.06.

The solution for V_p and C_p can be shown to be

$$C_p = \frac{2}{RN^2}\left[(F-1)\frac{L}{R} - T_D\right],$$

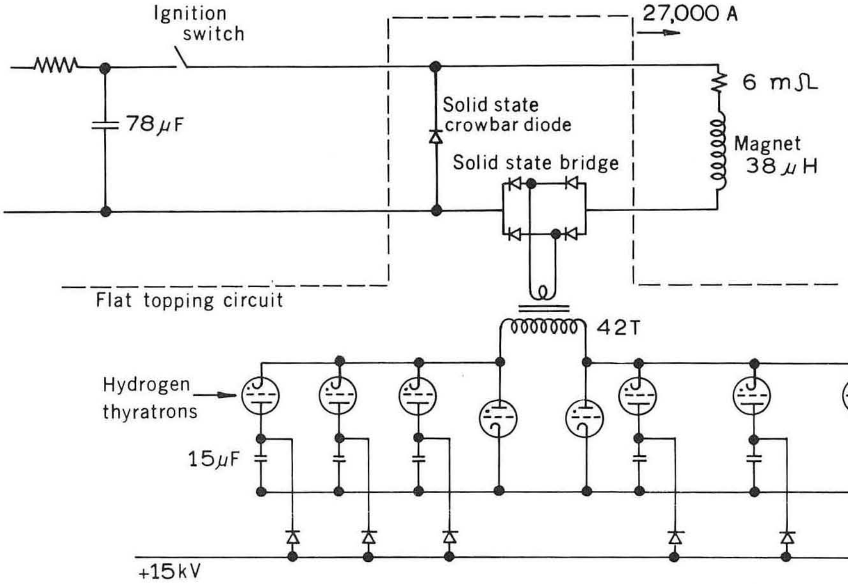
and

$$V_p = NI_0R\left[1 + \left(1 - \frac{T_D}{L(F-1)}\right)\right]^{-\frac{1}{2}}.$$

The values L, R, and F are design parameters determined by the coil circuit, and T_D is determined by the minimum deionization time of the thyratron. The turns ratio N is determined by the choice of an operating voltage for the thyratrons and storage capacitors.

Conclusion

The experimental behavior agreed with the above theory. The current waveform (Fig. 4) shows the current in the magnet with and without "flat-topping".



XBL692 4447

Fig. 1. Schematic of flat-topping circuit.

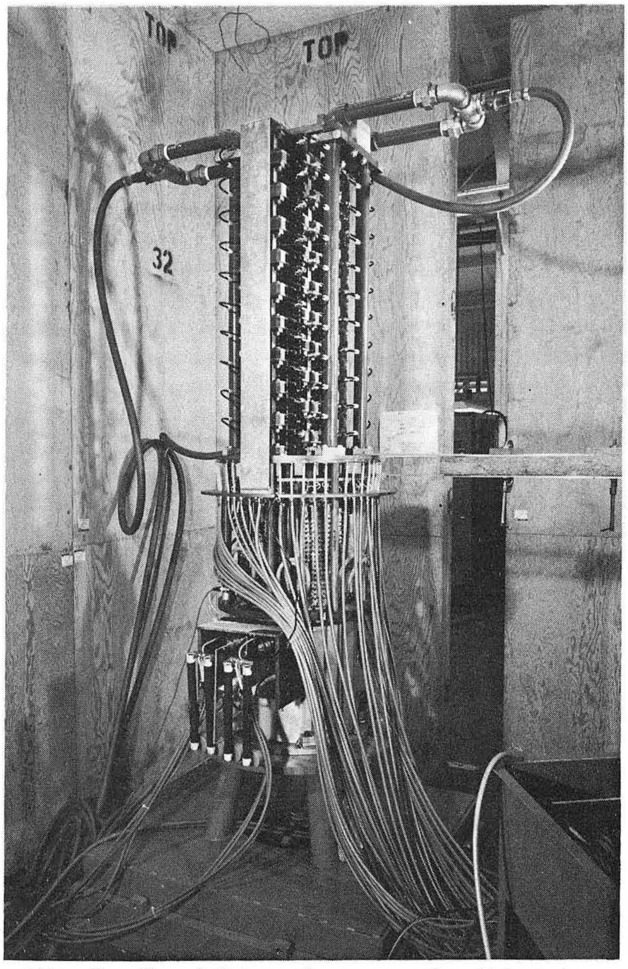
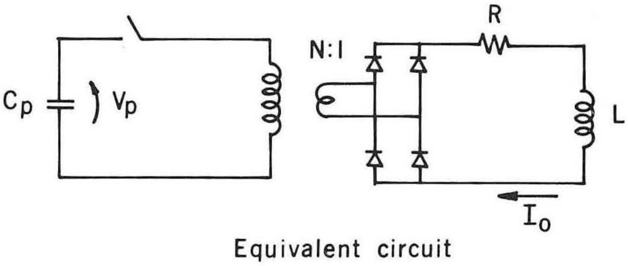


Fig. 2. Coaxial transformer and solid-state diodes.



XBL 692 4448

Fig. 3. Equivalent circuit of flat-topping circuit.

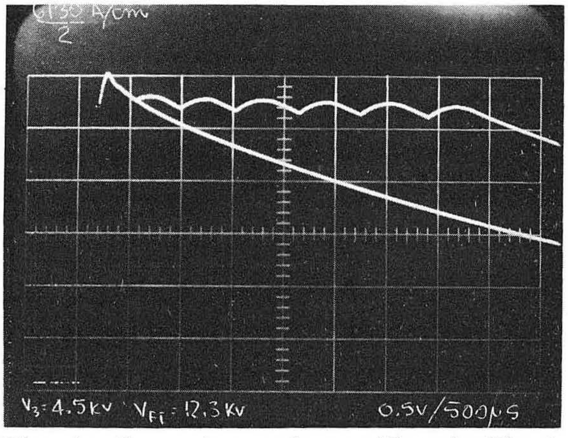


Fig. 4. Current wave form with and without flat topping.

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720