BNL-104497-2014-TECH

AGS/AD/Tech Note No. 63;BNL-104497-2014-IR

POWER SUPPLY SYSTEM FOR H-10 SEPTUM MAGNET

J. G. Cottingham

July 1969

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

AGS DIVISION TECHNICAL NOTE

No. 63

J.G. Cottingham and A.V. Soukas
July 28, 1969

POWER SUPPLY SYSTEM FOR H-10 SEPTUM MAGNET

General

The H-10 septum magnet now being developed has the following electrical parameters:

L = 9.15 microhenries

R = 1.65 milliohms

A peak current of 18,000 amperes is required to produce the necessary 22 mrad beam bend at 30 BeV/c. To accommodate a factor of safety, the power supply system will be designed to deliver 20,000 amperes. The current waveform must rise at a reasonable rate to the operating level and then remain flat for 0.5 milliseconds (with possibility of later being expanded to 0.75 milliseconds), and then return to zero. This must repeat at 100 millisecond intervals for four pulses, which in turn repeats every two seconds.

The proposed power system is shown in simplified schematic form in Fig. 1. The heart of the system is the oscillatory circuit composed of C1, SCR1, the connecting power cable and the magnet load inductance. The cable connecting the magnet load to the power system is 75 ft long and when assembled from six groupings each one composed of four 4/o cables, the series inductance becomes 0.98 microhenries and the series resistance becomes 0.61 milliohms. The value of C1 is chosen to accommodate a total maximum series inductance of 15 microhenries. If C1 is charged to 800 volts, the ringing current will reach 20,000 amperes in 1/4 period or 590 microseconds. When the peak current is reached, SCR2 is fired. The current from the lumped parameter delay line is matched to the load current, therefore, maintaining a constant voltage on C1, and if this equals the iR drop in the load circuit, di/dt will be zero as desired. This match is accomplished by adjusting the value of C1 and the firing time of SCR2. The length of the delay line determines the length of the flat top. Initially, we propose 500 microseconds with space and charging reserve for expansion to 750 microseconds.

When the reflection from the open end of the delay line returns, the conduction of SCR2 is extinguished. The voltage on the delay line has been reversed. Load current is now supplied by C1 and the ringing process continues until the load current reaches zero and SCR1 extinguishes. The voltage on C1 is now also reversed. Approximately 80% of the initial stored energy resides in the various capacitors (C1 and the delay line). The ringing circuit through the "fly back" inductor and SCR3 restores the proper voltage polarity. The capacitor voltage at the end of the pulse should reach 660 volts assuming 800 volts initially.

The losses incurred during the load pulse and fly back are restored by the charging system. It consists of a simple RC charging circuit with SCR4 starting the charging process and SCR5 terminating it. The series limiting resistor has several taps to accommodate initial turn-on and longer repetition periods.

Precise control of the load current pulse amplitude is accomplished by controlling the firing of SCR5. Voltage leakage on the capacitors even for a full two seconds should be $< 0.1\%$. If the capacitor leakage should exceed expectations, a small regulated 800 volt power supply can be procured and used to regulate the capacitor voltage during the rest period.

A 3 microhenry inductor is in series with SCR2 to limit its di/dt value. This inductor working with C1 also serves as a very effective ripple filter during the flat top portion of the load pulse. With a ten section delay line designed for 500 microseconds total period, the fundamental ripple frequency should be 20 KHz. The filter attenuation for this frequency is 470. Therefore, assuming 10% raw ripple on the delay line, the ripple voltage on C1 is 80/470 or 0.17 volts. If the total series load inductance is 15 microhenries, the ripple current will be 90 milliamperes. This should be small enough.

Parallel Circuits

It is not possible at present to purchase SCR's with 20,000 ampere peak current ratings, therefore, the system must be designed in subdivided groups which will deliver current in parallel. Both Westinghouse and International Rectifier Corp. offer SCR's with peak surge ratings near 5,000 amperes. Larger SCR's are advertised but full technical specification data does not exist. This design concept will be based on the 5,000 ampere cell; typically the Westinghouse type 272. In order to avoid employing the SCR's at their voltage and current ratings simultaneously, six parallel circuits are proposed each delivering 3,333 amperes. C1 must be subdivided into six packages and six delay lines are required each with its associated SCR2. This subdivision has the added advantage of forcing current sharing. The total cost of components is not significantly increased by this subdivision since the total stored energy is the same.

A single charging system is employed, since coupling diodes as shown in Fig. 1 provide the necessary isolation.

The fly back switch SCR3 cannot be a single SCR but must be two in parallel. In this multiple arrangement of SCR3, additional diodes which are not shown in the schematic will have to be used for isolation.

Components

1. SCR

The SCR's which are at present purchasable have voltage ratings up to 1,500 volts, which is twice the voltage employed in the system. This is a satisfactory ratio for hold-off in the forward direction but not satisfactory in the reverse direction. Therefore, each SCR will have a diode in series with it to enhance PIV ratings.

The following table represents a set of SCR's suitable for this application. Detail design may reveal other choices.

Function	No. in Parallel	No. in Series	Type	
SCR1	6	1	Westinghouse	272ZK
SCR2	6	1	"	"
SCR3	2	1	"	"
SCR4	1	2	"	250ZK
SCR5	1	1	"	"

2. Delay Line

The proposed delay line consists of six units, each having 10 LC sections. The delay per section is 25 microseconds and the characteristic impedance, Zo, is 0.24 ohms. The ohmic resistance of each inductor must be less than three milliohms in order to conserve the stored energy.

3. Main Capacitor, C1

The main capacitor, C1, consists of six groups each containing 1,500 microfarad at 1,200 volts rating. If a series lead inductance of 1 microhenry is permitted for this capacitor, a strap resonant frequency of 1.5 KHz would result. This is a reasonable value for any good energy storage capacitor. We should specify 10 KHz lowest strap resonant frequency.

4. Fly Back Inductor

The SCR's employed in parallel to form SCR3 permit a peak current in the fly back inductor of 6,000 amperes. The stored energy in the inductor must equal that in the capacitors of approximately 6,000 joules. This requires an inductance of 333 microhenries.

If we limit the energy loss during fly back to 250 joules, the resistance of the inductor cannot exceed 1.76 milliohms.

Such an inductor can be air-core wound from 500 MCM cable. It would be approximately 6 ft in diameter, 8 in. high and consisting of 11 turns. Each turn will be composed of three cables layed together. Such an inductor could be placed in the overhead of the H-10 house.

5. Charging System

The charging system consists of a raw six-phase power supply capable of 900 volts and 150 amperes (135 kW). The 10 ohm series limiting resistor permits initial charging and is shorted after turn-on. The taps on the other limiting resistor permit operation under several different charging modes depending on the number of output pulses required per AGS pulse, and whether the delay line (flat top load current) is required.

Firing of SCR4 initiates the charging process. Firing of SCR5 terminates it by extinguishing SCR4. SCR5 is extinguished by its own ring. In this fashion, i.e., by accurate control of the timing of SCR5, we can obtain a precise, variable amplitude current output pulse.

Estimated Cost

Power supply 135 kW at $120 per kW	$16,200.00
Resistors at $45 per kW	450.00
SCR - 14 ea at $600	
2 ea at $410	
1 ea at $275	9,495.00
Capacitors 15,600 μF at 1200 V	15,000.00
Shorting contactor	250.00
Cable, 600 ft - 500 MCM	600.00
2000 ft - 4/o	800.00
Delay line inductors 60 ea.	3,000.00
Electronics (trigger chassis, etc.)	4,000.00
Miscellaneous hardware	3,000.00
	$52,795.00

Distr:

Department Administration
AGS Division

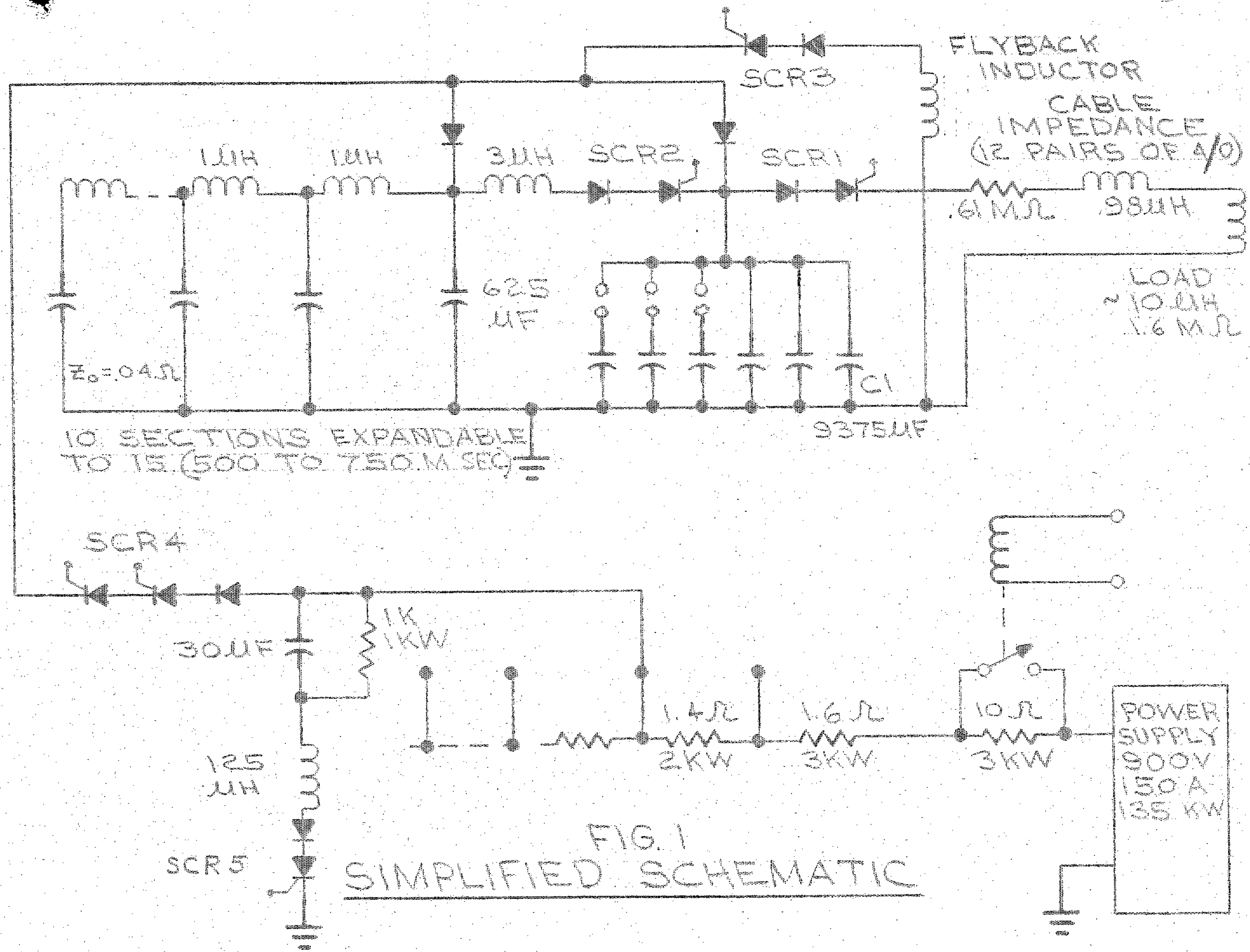

FIG. 1

SIMPLIFIED SCHEMATIC