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ELECTRICAL DESIGN OF A SMALL SOLID STATE ENERGY DISCHARGE POWER SUPPLY

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Summary

The construction of a solid state, voltage regulated energy discharge power supply with a dual output is briefly described. Each output operates at about 1800 V dc, and 7800 A peak. Charging voltage regulation, and set level, are obtained by means of a solid state relay at the primary site of the single phase high voltage rectifier transformer. This method yields a relatively inexpensive, simple system since it does not require phase control circuitry.

Application of the Power Supply

The power supply feeds short current pulses to aircore magnets located around a ceramic section in NAL's main ring beam pipe.

Two such systems located approximately 1/2 wavelength apart are used in synchronism to guide the circulating beam into an extraction channel.

They provide single turn extraction of up to three circulating beam bunches (4.8 μs spill length) or excite the 20 1/2 integer resonance for a spill length of 1 ms.

The Magnets

The magnets have two turns. They are constructed from 1/4 in copper tubing forming the edges of a 2 in x 5 in x 24 1/2 in long imaginary block. Two such magnets sit directly after each other and have an inductance of 2.5 μH each.

Building one large magnet would require twice the operating voltage, which is harder to handle with SCRs and makes the matching of other standard commercial components a little more difficult.

Current regulation of a few percent is adequate. The current must, however, be adjustable.

The Power Supply

Fig. 1 shows a schematic of the power supply. It has two identical outputs, which are fed from the same regulated dc source of 1800 V max. Both outputs are simultaneously discharged into the magnets.

Each magnet current (Fig. 4) looks like a half sine wave reaching a maximum peak value of 7800 A in 22 μ sec.

The average discharge rate is 1 shot per second or less. Momentary rates of 3 shots per second have been used. The stored energy is only about 100 J per output. Power consumption is small because of the low repetition rate and the small amount of stored energy. An ac feed of 120 V single phase is therefore very practical. The power supply is divided into two parts:

1. The controls and regulator (mounted in an easily accessible relay rack).
2. The rectifier discharge assembly (located close to the load).

The latter is an obvious requirement since long output leads can easily have an inductance of a few μH. It is for this reason that the output leads consist of 6 parallel coaxial cables. Care has also been taken to keep the inductance of the power supply low. The power supply self-inductance, including the 7 ft long output leads, was measured to be 0.5 μH. This value can be determined from the discharge frequency with a bolted short at the output leads.

Control can be local as well as remote from a computer which also monitors the output current and interlock status. Regulation takes place at the primary site of the HV rectifier transformer. It consists simply of an ac ON/OFF control by means of a solid state relay (optically isolated back-to-back SCR package), which needs only a few mW dc control power. It can, therefore, be driven by a small operational amplifier, as shown in Fig. 3. The adjustable reference and the feedback voltage from the power supply determine the point where the ac supply gets cut off and permits current control from about 0 to 100%. Fig. 4 a, b, c, and d show the dc voltage. Operation at high transformer tap and low reference setting gives the worst ripple, because the solid state relay stays on until the next zero crossing of the ac supply voltage. More overcharge is then supplied to the energy discharge capacitors. Fig. 5 shows a typical voltage at the primary of the transformer.

The discharge "switch" consists of two parallel sets of three regenerative gate SCRs in series, operating at about 4000 A peak each. These SCRs have $\frac{di}{dt}$ ratings of about 400 A/μ sec., and do not require a hard gate drive. However, a hard gate drive is employed to assure simultaneous turn on of the series connected SCRs. Fig. 2 shows the firing circuit. The primary windings of the pulse transformers are connected in series to make sure that all discharge SCRs get fired at the same time. Each SCR is paralleled with a 100 kΩ voltage equalizing resistor, a snubber of 33 Ω and 0.05 μF and a transient suppressor. A large voltage equalizing resistor should be chosen to reduce losses.

The SCRs are air-cooled and require only a few inch^2 of heatsink because the average losses are small, however, peak losses are in the order of 20 kW per SCR. Current sharing between the parallel SCR stacks is assurred by the 100 Ω resistors between the capacitors.

The diode resistor combination in parallel with the capacitors helps dissipate the 80% voltage reversal, which results at the end of a discharge cycle. Charge recovery[1] is not used because of the low repetition rate and low stored energy.

Acknowledgement

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Reference

1. Pulsed Septen Magnet and Power Supply For The 8 GeV Beam Transfer Line at the National Accelerator Laboratory, Visser, et al. IEEE Transactions On Nuclear Science, June 1971, Vol. NS-18, No. 3.

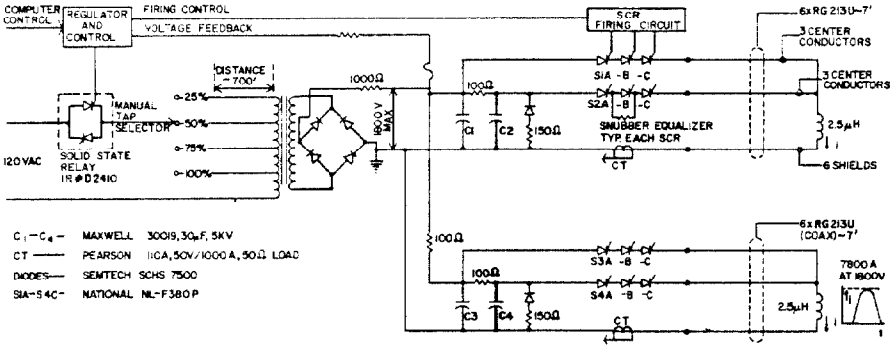
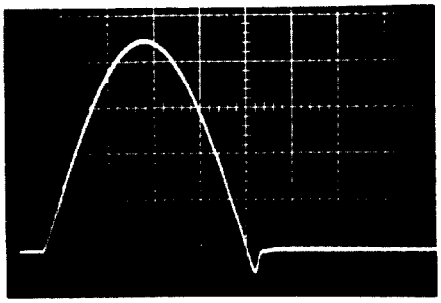


Fig. 1. Power Single Line Diagram



10 μs/div, ~1250 A/div

Fig. 4 Magnet Current at 1200 V

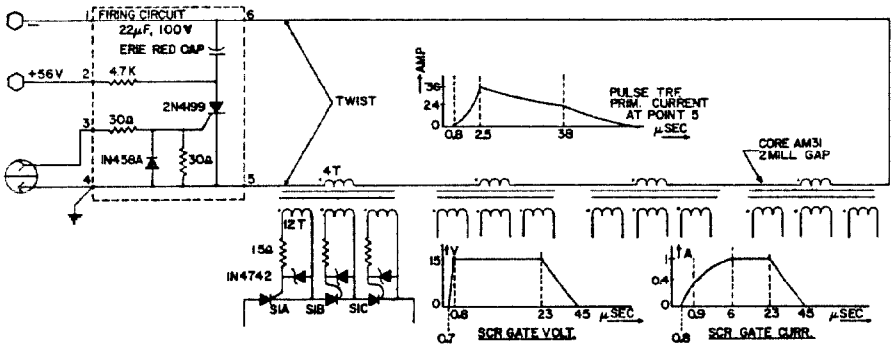
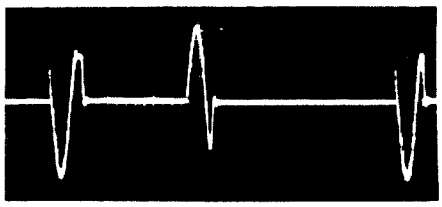


Fig. 2. SCR Firing Circuit Schematic



20 msec/div, 100 V/div

Fig. 5 Transformer Primary Voltage

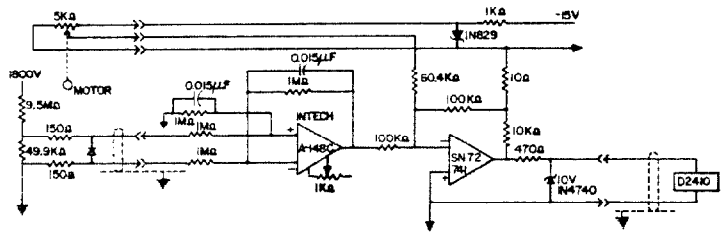
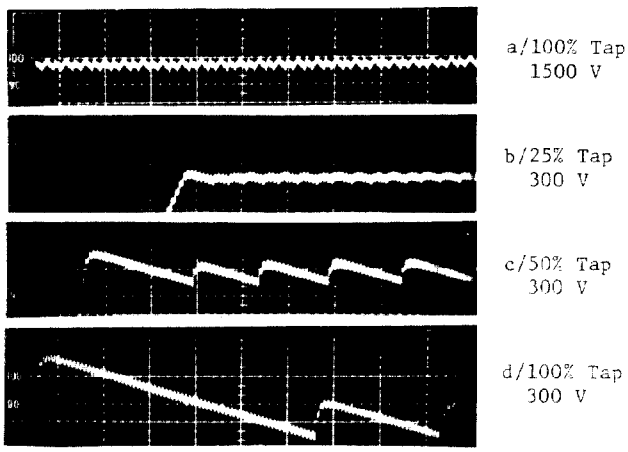


Fig. 3. Regulator Schematic



0.2 sec/div, 20 V/div

Fig. 6 DC Voltage at Various Settings