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POWER SUPPLY SYSTEM FOR BEAM STEERING*

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Summary

The power supply system for steering the Bates Linac beam provides continuous adjustment of the current from +2.5A to -2.5A per pair of coils at ±25 volts. A simple, inexpensive system has been assembled from off-shelf components. Separate controls for 26 pairs of coils are provided by means of power operational amplifiers and drivers connected in series with the coils across a common pair of ±30V busses. No current regulation is used. After coils and amplifiers have reached thermal equilibrium (about one-half hour at 2.5A) the current is stable within 0.5%.

Introduction - Requirements

The Bates 400 MeV linear electron accelerator contains 27 centerline waveguide sections at the leading end of which are mounted steering coils for guiding the beam to the next waveguide.

A set of four rectangular water-cooled helmholtz coils, 6" x 12" approximately, are mounted peripherally on each guide, one pair for horizontal steering and one pair for vertical steering. Three sets of coils are used in the gun, prebuncher, and buncher, and one-half set on beam bias. Following the buncher, the first five waveguides of the accelerator are twelve feet long and the next eighteen are twenty-four feet long. The drift space between waveguides averages two feet. Fifty-three channels of steering are required, two per waveguide and one for the bias.

The following specifications were established for beam deflection by the steering coils:

1) Continuously variable control in the positive and negative directions. Through zero desirable, but not necessary.

2) Beam deflection per waveguide ±3.2 mm (±3.2 mm corresponds to ±0.4 mrad for the 24-foot sections and ±0.8 mrad for the 12-foot sections).

3) Stability in 8 hours ±0.5%

4) Resolution ±0.5%

To obtain the same beam deflection, the current is proportional to the energy in the beam. The following currents were established for beam deflection at the various waveguides. The resistance R is that of one coil at the corresponding current. The increase in resistance for the identical coils of items 2, 3, and 4 is the result of greater heat dissipation.

	Maximum Current	R
1) Gun, bias, prebuncher, and buncher	<1A	8 ohms
2) Waveguides #0-#4 (12')	<1A	8
3) Waveguides #5-#16 (24')	2A	9
4) Waveguides #17-#22 (24')	3A	11

The current for each section can be linearly interpolated.

Power System Selection

Considering availability, the most obvious power system to select was one composed of voltage-regulated, bipolar power supplies, catalogue listed, one for each channel. The cost, however, was prohibitive, over \$80,000 - a factor of four above the amount budgeted. If the voltage regulation feature were eliminated, the cost would be reduced significantly. Hence, a cost analysis of a system using a simple rectifier and filter for each channel, with relays to shift polarity at zero, reduced the cost to \$40,000. A system using two well-stabilized (.01%) power supplies, one positive and one negative, to feed several bipolar operational amplifiers and controls was estimated to cost \$20,000.

Fig. 1 shows a Block Diagram of the system. The number of channels in one module is a compromise between the cost of wiring for the long distances to steering coils, and the cost of another module and power supplies. Cost of wiring over a long distance with a low voltage drop is appreciable. Module I at the low energy end of the accelerator has 30 channels, and Module II at the high energy end has 24 channels.

Circuit

The maximum power available from a catalogue-type operational amplifier was 62 watts, ±25V, ±2.5A. Fig. 2 shows the circuit schematic for a single channel of steering. Tests at 1.5A, the maximum output at 25V with the two coils in series, indicated a drift of ±0.25% over a 24-hour period. The warm-up time was one-half hour, much less than that required by other equipment in the accelerator. If necessary, a current-feedback system could be added at less than \$100 per channel.

The three distribution busses at the module are located close to the drivers. The voltages are remotely sensed at these busses for voltage regulation of the power supplies. To eliminate the effect of voltage drop by the relatively high current to the power amplifiers, the drivers are connected directly to the busses. Taking the utilization factor of the coils into consideration, the current rating of each power supply was set at approximately one-third of that required if all channels of one polarity were energized to maximum current.

All pairs of steering coils are connected in series and supplied from a single power amplifier for a maximum output of 1.5A. Up to the present, this has been sufficient for deflection. Should it later be found that larger currents are required in certain channels, a configuration that permits up to 2.5A in a coil by energizing each coil of one pair from a separate power amplifier can be used. See Fig. 3. Only one driver is used. The small difference in current which may develop in the coils is not expected to be troublesome. With a parallel configuration of power amplifiers connected to one coil, even larger currents may be obtained.

Steering in the Beam Switchyard

In the beam switchyard the requirements for angle of beam deflection were increased by 50% from those in the accelerator. Application of the same steering coils as those in the accelerator would have necessitated using a complex series-parallel arrangement of power amplifiers supplied by ±60V. Inasmuch as the coils had not been fabricated, a new set of coils were designed to be compatible for the series connection of one pair and yet be energized from a single power amplifier operating at 2.5A and 25 volts. This would permit the maximum power capability of the power amplifier.

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To achieve the higher magnetic field required for greater deflection, the number of turns in the coil was increased to 500 from the 300 in the accelerator-mounted coil. To eliminate water cooling of the coils the size of the wire was increased from #18 to #14. Further economy was realized by making the coil flat, instead of being formed to the contour of the 6" diameter drift space tube. Thus the cost of the coils in the switchyard was less than 40% of those in the accelerator. The 24-channel module used in the high energy end of the accelerator was also used in the switchyard.

In the accelerator, the two pairs of coils in one set were mounted peripherally at one location, completely filling the periphery of the circular waveguide. At the switchyard, pairs of coils were mounted on vertical and horizontal planes. To avoid physical interference, the vertical pair was displaced from the horizontal pair along the length of the drift tube. Aluminum cradles on which a pair of coils rested simplified the mounting so that the cradle-coil assembly could be moved from one position to another in a matter of minutes.

Conclusion

The feature of remote beam steering from the Central Control Room has been incorporated.[1] Operation of a pushbutton switch at the console selects the controls for the set of coils in which the currents are to be adjusted and monitored. The selection automatically connects one lever switch at the console to the controls for the horizontal coils, and one switch to the controls for the vertical coils. The lever switch drives a motor attached to the current-adjust potentiometer. One remote control system controls the accelerator steering and another the beam switchyard steering.

In more than three years of operation, this economical power system for beam steering has operated at maximum reliability, not experiencing a single failure

Acknowledgments

Dr. J. Haimson determined the design and current requirements of the steering coils in the accelerator, and Dr. S. B. Kowalski determined the magnetic field requirements in the beam switchyard. F. J. Fay, E. DeAgazio, and K. F. Richard assisted in the electrical and mechanical design. C. J. Martin of Tidewater Technological, Inc., helped design the driver circuit.

References

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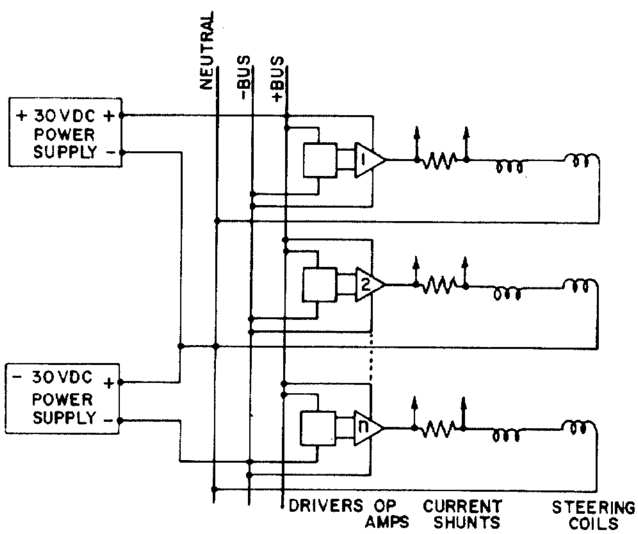

Fig. 1 BLOCK DIAGRAM
POWER SYSTEM FOR BEAM STEERING

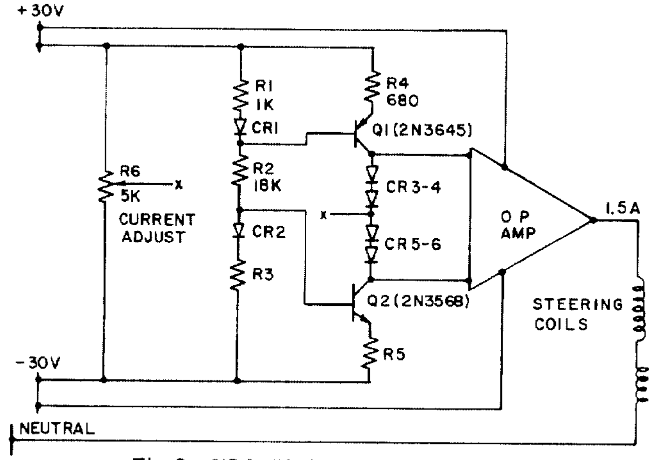

Fig. 2 CIRCUIT SCHEMATIC
SINGLE CHANNEL - 1.5A OUTPUT

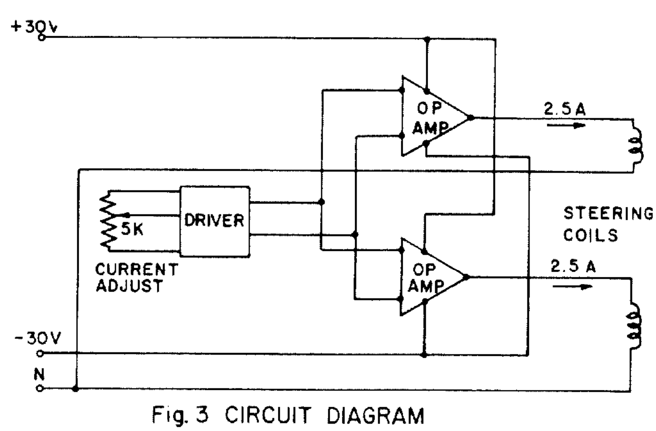

Fig. 3 CIRCUIT DIAGRAM
SINGLE CHANNEL - 2.5A OUTPUT