60 Hz FLUX PUMPS*

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Interest in flux pumps at Brookhaven arose almost simultaneously with the receipt in late 1965 of 1.27 cm wide Nb_3Sn ribbon that was capable of working at 500 to 700 A. Since we desired to run tests for periods of an hour or more at these currents, the problem of lead inefficiency with the associated helium loss was great. Now, the design of efficient leads for use up to 3000 A has become straightforward, but for steady dc operation of beam magnets above about 500 A, we are still interested in flux pumps.

From the start, we have concentrated on a pump design that could operate from 60 Hz, at first from a three-phase line, but in the latest pumps, from single phase. The cold part of the pump contains three parts: an air-core step-down transformer of ratio 120:1, and two identical switches that operate magnetically with no moving parts. These are wired as shown in Fig. 1.

Operation is as follows: An autotransformer (Variac) is used to control ac which is applied through a capacitor to the transformer. The capacitor provides 70-80° of phase shift in the current flow in the transformer primary. The secondary of the transformer has the two switch elements connected in series across it. The superconducting device or magnet is placed in parallel with one switch element. Each switch element is a length of fine, multistranded, soft superconductor (such as Pb30%Sn solder). The element can carry the full magnet current with no field around it, but is fully switched when immersed in a field of 600 to 2000 G. Each switching field is produced by a 1 in. bore air-core solenoid made of Nb48%Ti wire with extra spacing for helium flow. The solenoids are capable of cycling 0 to 10 kG to 0 at a 60 Hz rate (operating biased), but in switching use, 0 to 1.5 kG is about optimum. The switch magnets are driven in parallel from a second autotransformer. Each coil, however, has a diode in its circuit to bias it in one direction. A damping resistor is used across each coil to smooth out the diode action. The diodes are bucking so that the coils operate 180° out of phase. The total phasing is such that as one switch is energized and resistive, the transformer is drawing flux from space across the resistive element and into the SC circuit. On the next half-cycle, the first switch becomes SC and the second switch resistive. The transformer is now on the opposite swing so that it forces the flux through the second switch element and into the magnet.

In normal operation, the switch drive is adjusted with an oscilloscope to the point where the elements return completely to SC between cycles. The pumping rate is then fully adjustable with the transformer input control. To put the load, or magnet, into a persistent mode, the switches and transformer drive are turned to zero.

Two pumps of this type have been made. The first produced 1.5 W and was able to drive a 103 kG, 1 in. bore magnet normal, with a final current of 119 A. The second pump has larger switches and pumps at a 5 W maximum rate. The efficiency at present is not good — mainly because of losses in the switch elements. At maximum rate the efficiency is about 50%, while at one-half rate it appears to be somewhat better.

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Since a very small (approximately 0.5 W) pump will be used with each beam magnet, and only to counteract resistive joint losses, this efficiency is quite satisfactory.

A novel modification to the pump was suggested by K.E. Robins, namely, to add a second load magnet across the vacant switch. This has been tried and works as Robins predicted, both magnets being energized simultaneously at the same voltage.

A great deal of credit is due here to W.B. Sampson and K.E. Robins, who performed many of the preliminary experiments that led to this design.

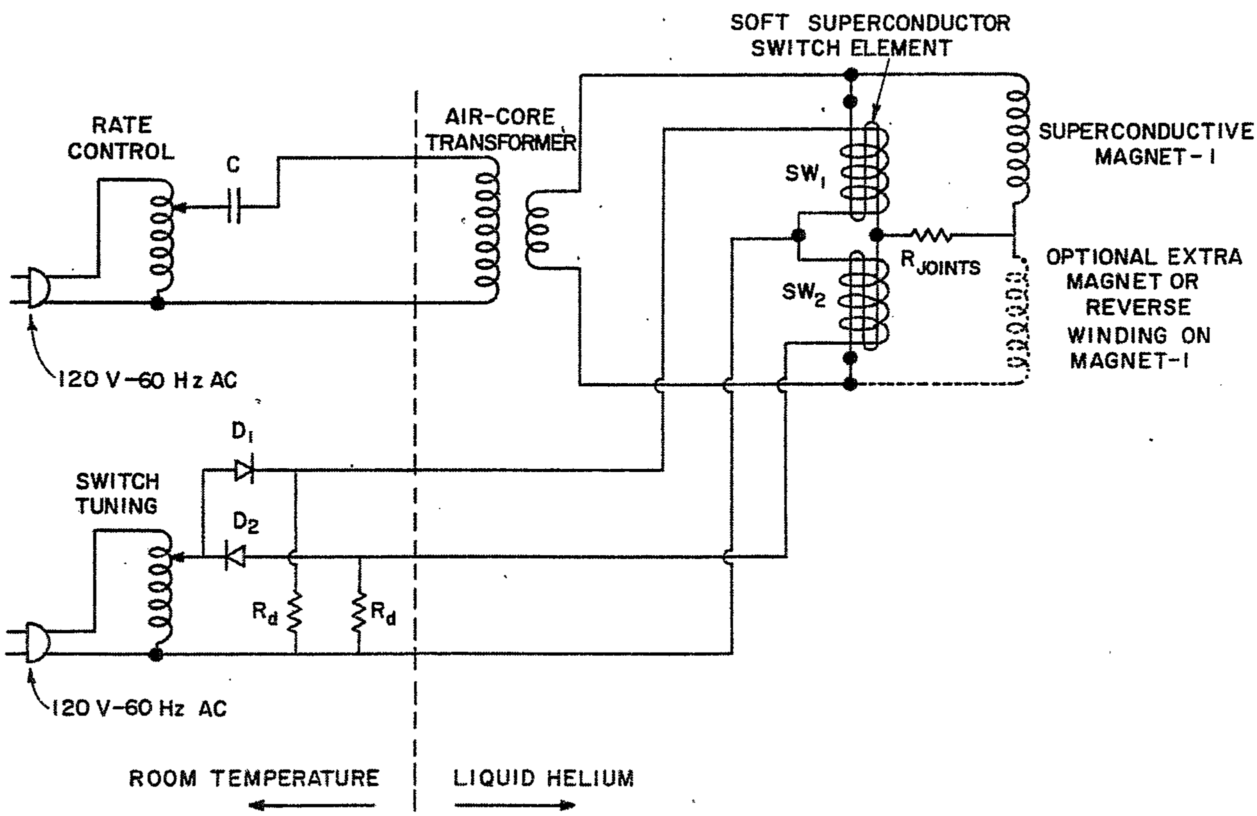

Fig. 1. Flux pump to make up resistive losses in dc beam magnet.