CONTROL OF TRIM COIL CURRENTS BY RHEOSTAT BRIDGES WITH EFFICIENCIES ABOVE 80%

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Summary

The 40 trim coil circuits of the 70-inch cyclotron being installed at the Naval Radiological Defense Laboratory are to be powered by a remote power supply which energizes 40 series-connected rheostat bridge circuits located on the cyclotron proper. The rheostat bridges will have a maximum power efficiency in excess of 80%.

Introduction

Forty separate trim coil circuits have been designed for the 70-inch cyclotron which is being installed as a part of the Neutron Radiation Facility at the Naval Radiological Defense Laboratory in San Francisco, California. The current in any trim coil circuit may need to be set at any value from full positive to full negative, depending on the energy and type of particle being accelerated. The maximum trim coil currents range up to 750 amperes.

The cyclotron is mounted on a rotatable support which can be turned through 300°. Neutron production rates of 10^{15} per second are anticipated with a corresponding radiation atmosphere within the cyclotron vault of approximately 10^4 rads/hour.

The high trim coil currents and the rotatable mount prevented the use of individual remote power supplies, while the radiation precluded the use of individual local power supplies.

Bridge Circuit Development

The carbon compression rheostat was the only type rheostat located with the power and current capabilities required. Either a bridge circuit or a parallel series arrangement with shorting and polarity reversing contactors would provide a remotely controllable, radiation resistant distribution system. Cost, size and ability to provide continuous adjustment from maximum positive to maximum negative currents favored the bridge circuit. A constant current power supply driving a series connected bank of bridge - trim coil circuits as shown in Figure 1 allows adjustment of any one trim coil current without affecting the current through the remaining circuits.

Maximum efficiencies are obtained by adjusting the rheostat drive system such that all rheostats of a bridge are at minimum resistance for the zero load (trim coil) current condition. The required trim coil current and polarity are obtained by decreasing the compression of either R_1 or R_2 of Figure 1. The efficiency at maximum load current (η) can be shown to be

$$\eta = \frac{K(C+1)}{2CK^2+(C+1)K+1} \qquad (1)$$

where

$$K = R_1/R_L \text{ and } C = R_{2\,max.}/R_{1\,min.} \qquad (2)$$

Taking the derivative and setting it equal to zero gives a maximum efficiency point at

$$K = \frac{1}{\sqrt{C}} \qquad (3)$$

If this is substituted into Equation 2, the maximum efficiency obtainable for any rheostat maximum to minimum resistance ratio is

$$\eta_{max.} = \frac{C+1}{4\sqrt{C}+C+1} \qquad (4)$$

Using a commercial rheostat with a maximum to minimum ratio of 50 allows a maximum efficiency of 64 per cent. A ratio of 200:1 would give a maximum efficiency of 78 per cent and a ratio of 1000:1 gives 89 per cent.

In order to improve the efficiency, a development program was undertaken to economically increase the resistance ratio. The extended range is obtained by inserting a spring between the carbon plates, alternating top and bottom as shown in Figure 2. Thus at the point where the resistance of standard rheostats becomes intermittent, the extended range rheostat yields a steady increase in resistance by separating alternate plate edges, hence decreasing the interface area and increasing the length of the current path. In preliminary tests using rubber springs, a maximum to minimum resistance ratio of 800:1 was obtained.

An engineering model bridge was constructed with metallic springs and 7 plates per bridge leg, and tested up to 700 amperes. This resulted in a minimum leg resistance of 0.9 milliohm and a maximum resistance of 212 milliohms (a ratio of 236:1). The contact plates were water-cooled and no heat problems were encountered while varying the load current from zero to 650 amperes. The load current was recorded on a strip chart recorder and for most current settings the thermal drift remained within .5 per cent of the adjusted value after 4 minutes.

Construction of a production prototype bridge is scheduled to start in March 1965. Insulated metallic springs will be tested and are expected to increase the resistance ratio to over 500:1 and an efficiency above 85%.

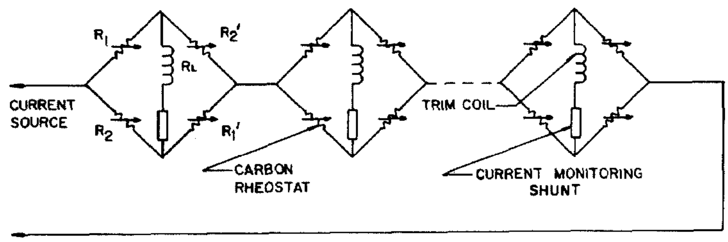

Figure 1. Series Connected Trim Coil - Rheostat Bridge Circuits.

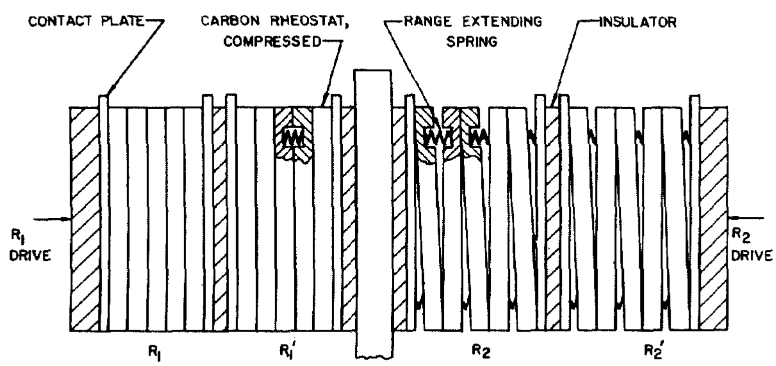

Figure 2. Rheostat Bridge, Simplified Mechanical Configuration.