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MAGNET POWER SUPPLY FOR
ALPHA-PARTICLE SPECTROMETER II

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ABSTRACT

A current-regulated power supply has been built to deliver current, continuously variable from 0 to 600 ma, into a load of 4000 ohms. The system is stable to approximately 1 part in 10,000 over long periods of time. Stability has been achieved by using a series tube type of regulator with both a dc amplifier and a chopper amplifier combined to give both long-time and short-time stability.
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I INTRODUCTION

Alpha-Particle Spectrometer II is a 180° magnetic deflecting machine with a 35-cm orbit radius, and is designed for a maximum field of 15,000 gauss. The coil has a total resistance of about 4,000 ohms and requires a maximum current of 600 ma. The machine may be operated with either a photographic plate or a scintillation counter as the receiver. Because exposures on the photographic plate receiver may run in excess of 24 hours, it is necessary that the power supply for the magnet have a long time stability, on the order of one part in 10,000, to maintain the resolution of the system. It was thought desirable that the magnet supply should be operated from an unregulated line because of the large power requirement of the system (about 4000 watts), and because this would add flexibility. This means that the power supply should be able to maintain the magnet current within the specified variations under long-time line variations, short-time periodic line variations, and rapid transient variations.

In order to maintain a uniform, noise-free ground for the entire system, the installation has been provided with an isolated power system, and a single ground has been established separate from other grounds in the building and isolated from the ground normally established for the incoming power lines. Isolation from the power line is accomplished through special isolation transformers.

II DESCRIPTION

The power supply for the unit consists of a bridge-type rectifier and a filter capable of delivering 4,000 v at 600 ma. The current (I_m) for the magnet passes from the positive end of the supply through four type 304TH V1-V4 transmitting tubes in parallel. From the 304TH's the current passes through a 250-ohm precision oil- and water-cooled resistor which provides the signal voltage to control the unit. Then it passes through the current-metering system to the magnet and returns to the negative side of the power supply. (See Fig. 1) The system is grounded at the negative end of the meters in order to keep the metering near ground potential, and to keep the controlling amplifiers at a low impedance to ground so that there will be no spurious signals picked up and transmitted to the magnet. The signal from the 250-ohm resistor R1 is applied through a suitable amplifier to control the grid potential of the control tubes V1-V4 as described below.
A 170-volt table reference voltage is added to the signal from R1, and a potential divider consisting of R2 and R3 is placed across the two of them, forming a bridge. The legs of the bridge are formed by

(a) the signal resistor R1,
(b) the reference voltage,
(c) R2 and the section of R3 between R2 and the tap,
(d) the section of R3 between the tap and R1.

The points between which a null is to be established are the tap of R3 and the junction between R1 and the reference voltage.

If this null is established then the ratio of the voltage across R1 to the reference voltages is equal to the ratio selected on the potential divider. Thus R3 is used to select the desired magnet current.

The error voltage across the null points of this bridge is applied to two different amplifiers, each of which serves a separate function in controlling the current. The first of these is a conventional dc amplifier. The signal is applied from cathode to grid of the first stage through a 1-μf capacitor and the plate of the second tube is connected to the control tubes V1-V4 through a 500-v biasing supply. Normally the coupling condenser would not be used on the input to this amplifier, but since there must be a few volts bias between the grid and cathode of the first tube, and as this bias requirement varies with time and temperature by a few millivolts, it was found necessary to apply a correcting voltage so that the bridge might be kept at an absolute null. This was done by adding a stabilizing amplifier to the circuit to supply the necessary difference between the operating bias and the null for the bridge. The error voltages are applied to a 60-cycle interrupter and the resulting ac voltage is amplified. The resulting 60-cycle wave is synchronously rectified and applied as a charging current into the coupling capacitor of the dc amplifier, thus supplying the necessary bias and correcting for any variations that would alter the null of the system. The net result is that any rapid changes in the system are corrected by the dc amplifier, and slow drifts are corrected by the stabilizing amplifier.

It was found, upon putting the system into operation, that the magnet was so inductive that it generated very high voltages upon any change in current. These voltages were high enough to throw the amplifier out of its range of operation and cause sustained oscillations. It was found necessary to introduce a feedback voltage from the negative end of the magnet to the amplifier input through C1 in order to correct these surges and prevent oscillation.
Fig. 1 Simplified schematic drawing of power supply for magnet of Alpha-Particle Spectrometer II.
III PLATE SUPPLY

The plate supply consists of four separate units, since the bulkiness of the components precluded mounting them as a single unit. (See Fig. 2) These units are (1) 28A powerstat, (2) rectifier chassis, (3) plate transformer, and (4) filter. The powerstat is provided so that the supply voltage may be adjusted in order that the plate dissipation of the control tubes not be exceeded. The line voltage enters through the rectifier panel, which is provided with a time-delay relay so that the supply voltage will not be applied to the rectifier tubes until they have had adequate warm-up time. An interlock link is also provided so that the supply will be turned off in event of magnet overtemperature, and also to prevent access to the high-voltage circuits while the supply is on. The rectifier itself consists of four type 872 mercury vapor tubes connected as a bridge rectifier. They are supplied through adequate fuses from the power transformer as shown in Fig. 2. The filter is a conventional choke input type with a substantial bleeder to discharge the capacitors when the unit is turned off and to drop the open-circuit voltage of the supply.

IV REGULATING TUBES

The four control tubes are mounted on a separate chassis provided with a fan to keep the tube envelope and connections cool. (See Fig. 3.) This chassis also contains a current meter and a voltmeter that reads the voltage drop in the tubes. These meters are used to check the operation of the tubes so that they do not exceed their rated dissipation. The necessary supply voltage may be computed from the following figures:

1. Voltage drop in the magnet (4000 ohms at 600 ma) 2400v
2. Voltage drop in the sampling resistors (250 ohms at 600 ma) 150v
3. Plate supply drop, no load to full load 400v
4. Voltage drop in control tubes for adequate control at 600 ma 1000v
   Total required supply voltage 3950v

The maximum dissipation of the regulator tubes in running from no load to full load is \( \frac{E_0^2}{4R} \) where \( E_0 \) is the supply voltage and \( R \) is the total external resistance, including the power supply impedance.

The maximum plate dissipation is then

\[
\frac{3950^2}{4 \times 4000} = 980 \text{ watts.}
\]

The regulator tubes have a rated plate dissipation of 300 watts each or a total of 1200 watts. This leaves a margin of 20% for variation in the line and for unequal distribution of current between tubes.
Fig. 2. Over-all schematic of power supply.
Fig. 3. Schematic of regulator-tube chassis.
The control amplifier (the dc amplifier described in II) is designed so that there is a common point to which all the components of the system are tied. (See Fig. 4.) The components referred to are (1) the dc amplifier, (2) the reference voltage, (3) the sampling resistor, (4) the control tubes, (5) the stabilizing amplifier. These can then all be tied to a common subchassis to eliminate the introduction of spurious signals and to prevent capacitive feedback from the various parts of the circuit through stray capacities between power supplies and grounds. The dc amplifier is operated from its own power supply, which is voltage-regulated by the tubes V2, V3, V4, V5, and V6, Fig. 4. This supply also provides a stable source for the reference voltage produced across V7 and V8. This reference voltage is very stable if the current in the two 85A2 voltage regulator tubes is kept at a fixed value and the tubes are adequately protected from heat and light.

The bridge circuit described in II is shown here by the sampling resistor connected across BP1 and BP2, the reference voltage, V7 and V8, and the potential divider R8, R9, R12, and R13. Resistors R12 and R13 are the coarse and fine current controls. A voltmeter is placed across the terminals of the sampling resistor 12 so that the current in the resistor may be read on this panel. This is a 150-v meter scaled to read 0 to 600 ma. The input to the stabilizing amplifier is made through PG1 and the output from the stabilizing amplifier comes in on PG2 and provides a charging current into the coupling capacitor C4 in the manner described in II.

Units V9 and V10 make up the dc amplifier. It can be seen from the voltages indicated on Fig. 4 that the plates of V10 have a possible excursion of about 450v. That is, the voltage cannot go higher than the plate-supply voltage of 600v or lower than about 60 or 70 volts above its cathode, which is 85 volts above the negative end of the supply. Since this excursion must be applied to the grids of the 304TH control tube, but must descend from 0 volts to about -400v, it is necessary to place a fixed negative voltage between the plate of V10 and the output to the control tube grids (PG3). This is done with an isolated power supply of 500v, shown across C7 of Fig 4.
Fig. 4. Schematic of central amplifier.
VI STABILIZING AMPLIFIER

The stabilizing amplifier (Fig. 5) is an ac amplifier for the 60-cycle square wave produced by a 60-cycle vibrator. This signal is synchronously demodulated and applied to the output terminals. The operation is as follows:

During the first half of the cycle, the input capacitor $C_1$ is allowed to change to the error signal voltage, and the output capacitor is grounded at one end and allowed to change to the plate voltage of $V_3$. During the next half cycle the incoming dc signal is grounded so that a voltage appears at the grid of $V_1$ equal to the incoming signal that has charged $C_1$ and opposite in polarity. At the same time $C_8$ is detached from ground so that a voltage through $R_{15}$ appears at the output terminal Pin A of PG2. This voltage is equal to the change in the input to $V_1$ multiplied by the gain of the amplifier and is of the same polarity as the incoming dc signal. Thus voltage pulses of half-cycle duration and of the same polarity as the incoming signal are applied to the output terminal to charge the coupling capacitor described in section II.

VII SAMPLING RESISTOR

The 250-ohm current-sampling resistor is made of No. 24 manganin wire wound on a 2-3/4-inch od bakelite tube 14 inches long. It is hand-wound to 250 ohms ± 1%. This resistor is mounted by means of its terminals to copper straps attached to spark plug terminals in an oil-filled tank. The tank contains a cooling coil consisting of a helix of 3/8-inch copper tubing passing through the center of the resistor form. Cooling water is passed through this tube at the rate of 1 gal/min. This limits the temperature rise in the water to less than 1°F when the resistor is dissipating its maximum power of 90 watts.

VIII METERING SYSTEM

The metering panel contains a Weston Model 93 dc milliammeter, 0 to 75 ma, 0 to 150 ma, 0 to 300 ma and 0 to 600 ma. (See Fig. 6.) In series with the meter are a 2-ohm and a 5-ohm metering shunt. The 2-ohm shunt is connected to a plug PG2 so that the potential drop may be measured accurately with a Rubicon potentiometer and galvanometer connected externally. The potential across the 5-ohm shunt is compared with a continuously variable voltage from a potential divider powered by a 3-v dry battery. The difference is read on a -50 to +50 microameter so that the voltage may be "zeroed in", and then the difference potential can be switched to a 10-mv Speedomax Recorder connected to PG1 so that the current drift may be continuously monitored. A switch is provided so that the reference voltage from the potential divider or the top of $R_{11}$ may also be checked with the potentiometer at PG2.

Other meters are provided in the control tube chassis and on the control amplifier as previously described.

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Fig. 5. Schematic of stabilizing amplifier.
Fig. 6. Schematic of magnet-current meter and vernier.