A Magnet Current Stabilizer

J. L. Lawson and A. W. Tyler
University of Michigan, Ann Arbor, Michigan

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A precision current stabilizer is described which is suitable for controlling an electromagnet. The circuit is adaptable to a wide range of current values. Applications to a cyclotron and to a beta-ray spectrometer are discussed. Currents have been stabilized over a period of several hours to better than 1 part in 50,000.

THERE are many pieces of apparatus requiring a magnetic field which must be kept constant over a prolonged length of time. In general this is satisfactorily accomplished by maintaining a constant exciting current in the coils of an electromagnet. The best method of stabilizing the magnet current is determined largely by the particular use to which the magnet is to be put and by the general features of the exciting circuit. Two stabilizers will be described which operate in the same fashion but which have been modified to suit the requirements of a cyclotron magnet and the magnet of a beta-ray spectrometer.

The magnet of the Michigan cyclotron is excited by a separate generator. The magnet current is between 150 and 250 amperes and must be stabilized to one part in 5000 for satisfactory performance. The fundamentals of the stabilizer are as follows: The difference between the magnet voltage and a bucking potential is amplified by a direct coupled amplifier which ultimately controls the excitation to the generator supplying the magnet power. Thus as the magnet voltage rises the resultant action of the direct coupled amplifier reduces the excitation to the generator. This is then a degenerative stabilizer in the sense given by Hunt and Hickman,[1] whose stabilization ratio is approximately the gain of the direct coupled amplifier and generator. This action should be made as rapid as possible in order to counteract sudden changes in e.m.f. In order to maintain a constant stabilized voltage it is essential that changing characteristics of the initial amplifier tube cause negligible changes in the stabilization point. This will occur if the magnet voltage is large compared with the grid bias on the initial amplifier tube. The current through the magnet is made to control the value of the bucking e.m.f. by a galvanometer and photo-cell arrangement. Thus the stabilizer fundamentally controls the magnet current. The galvanometer and photo-cell action can be made relatively slow, as this has been installed only to compensate for slow drifts due to heating and aging.

It can be seen that the field and armature of the generator must be separated by the d.c. potential involved in the amplification. Since it is usually desirable and sometimes necessary to ground the magnet, one must provide for separate field excitation for the generator from an ungrounded source or design an amplifier that does not require a d.c. potential between the initial and final stages. Henderson and White[2] have overcome this difficulty by using a grid controlled rectifier circuit. However, Vance[3] has described a circuit in which the first stages of the direct coupled amplifier are used to modulate an audiofrequency amplifier fed from a suitable oscillator. The modulated audiofrequency output is then fed through a transformer or condenser, which serves to block the d.c. potential. It is then rectified, filtered and used to control an element in the circuit at any potential. This is easily adapted to control the field excitation to the generator.

In a control of this type a certain amount of hunting is introduced by the time lag in the compensating action. The voltage may fall below the normal value if compensation does not take place instantaneously. When such compensation does take place it continues for a short time after

[1] F. V. Hunt and R. W. Hickman, Rev. Sci. Inst. **10**, 6 (1939).

[2] M. C. Henderson and M. G. White, Rev. Sci. Inst. **9**, 19 (1938).

[3] A. W. Vance, Rev. Sci. Inst. **7**, 489 (1936).

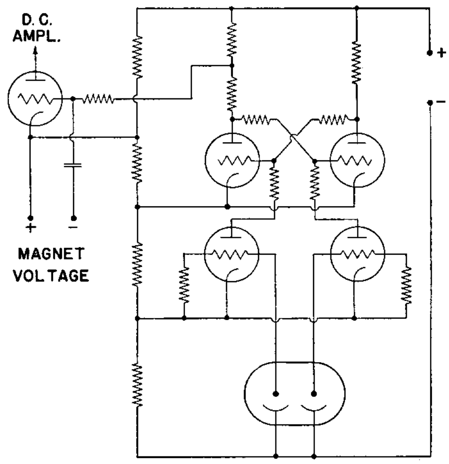

FIG. 1. The photo-cell circuit.

the voltage is returned to its original value. Thus the voltage oscillates or hunts about its normal value. The amplitude and frequency of this oscillation depend upon the over-all gain and time lag in the circuit and upon certain other design factors. In general hunting is less noticeable with a small time lag and low over-all gain. A high audiofrequency provides a sufficiently small time lag and is simpler to use than a radiofrequency.

The actual method by which the galvanometer and photo-cell is made to control the bucking e.m.f. is not particularly important. One such method, which has been adopted because of its convenience, is shown in Fig. 1. A beam of light from the galvanometer illuminates the elements of a twin photo-cell. This photo-cell is made to control a pair of tubes which act very much as the scale of two vacuum tube counting circuits. That is, when the light swings off the photo-cell, the one or the other of these tubes remains conducting depending upon which element of the photo-cell was illuminated last. This either charges or discharges a condenser in the grid circuit of the first stage of the direct coupled amplifier, the voltage across the condenser serving as the bucking e.m.f. to the magnet potential. An advantage of this circuit lies in the fact that once the light has illuminated the photo-cell it may be swung off in either direction without danger of the stabilizer losing control. Here, as before, hunting will be experienced due to the lag in the action of the galvanometer. To minimize this effect two things have been done. First, the changes made in the bucking potential by the photo-cell arrangement have been made slow by making *RC* large (of the order of 4 seconds). Secondly, the galvanometer is fed not only by the e.m.f. developed across a resistance, *R*, by the magnet current, but also by the

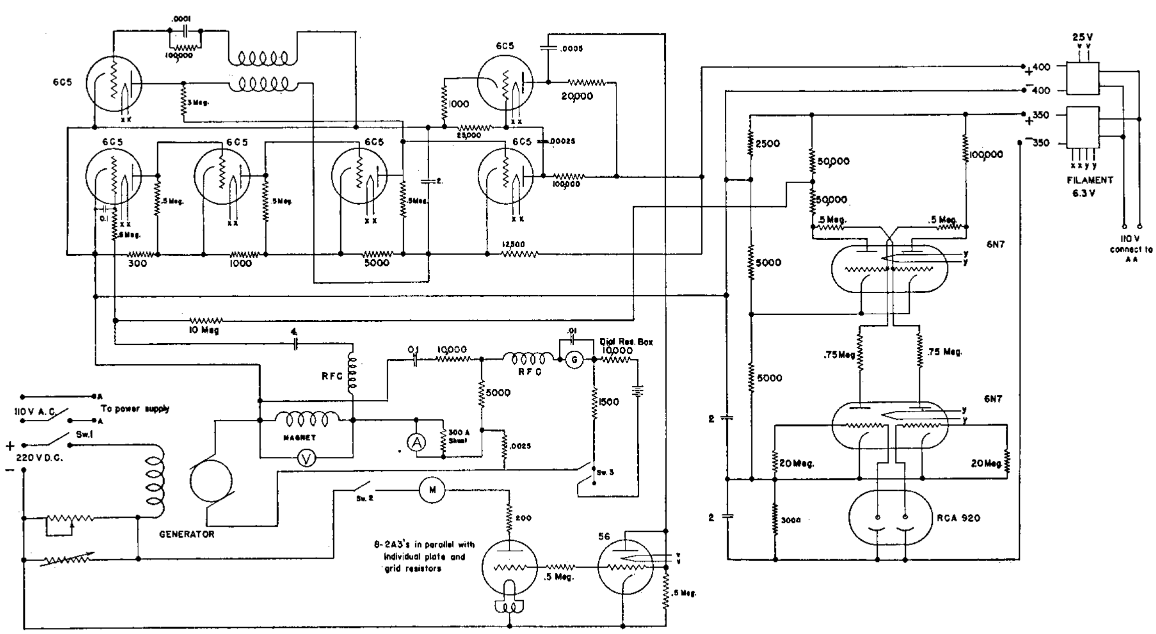

FIG. 2. Magnet control circuit for the cyclotron, University of Michigan.

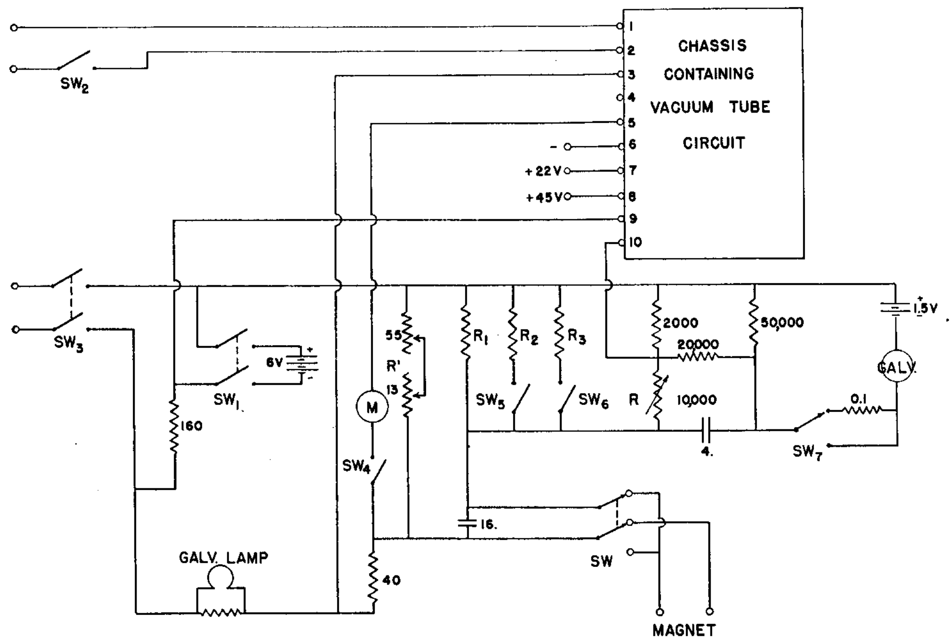

FIG. 3. Magnet control circuit for the beta-ray spectrometer, University of Michigan.

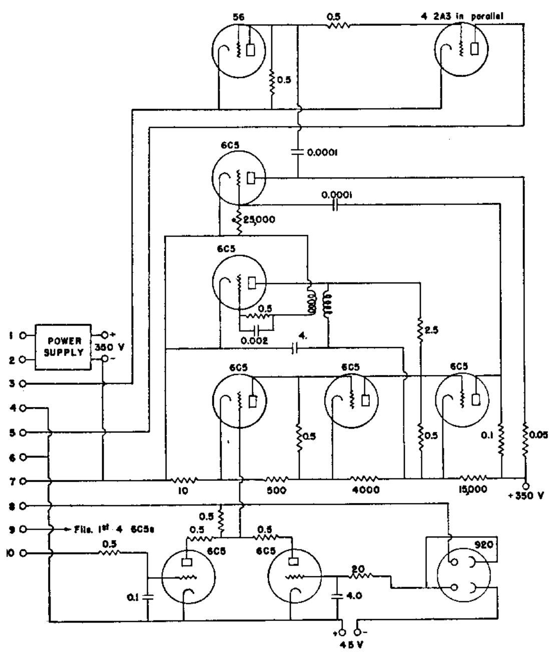

FIG. 4. Vacuum tube circuit of magnet control.

potential across the magnet through a condenser. This condenser greatly reduces the hunting in the galvanometer circuit, and yet plays no part in the average stabilized current which is still determined only by the e.m.f. developed across R.

The complete schematic diagram of this current control is shown in Fig. 2. All of the previously discussed circuits have been incorporated. Radiofrequency filtering has been placed in various positions in order to eliminate the effects of the cyclotron oscillators. The places where this filtering is most effective is dictated by the particular layout of the oscillators and the amount of other shielding employed. This stabilizer has operated satisfactorily for over a year.

The magnet of the Michigan beta-ray spectrometer requires a maximum excitation current of about 5 amperes, hence may be conveniently excited from the 220-volt d.c. mains. The current can be stabilized by the general methods just described, but certain features have been included which are not essential in the cyclotron magnet stabilizer. It is desirable to be able to change the stabilized current quickly to a new value and to provide for a more rapid stabilizer action.

The magnet current furnishes an e.m.f. across a series resistor which is applied to the grid of the first stage of a direct coupled amplifier. The output of this amplifier is used to control the grid bias on a power amplifier which acts as a series resistance in the magnet circuit. Because the potential difference between the initial amplifier tube and the power amplifier output is determined by their positions in the magnet circuit, the amplification scheme must allow for this potential difference. This is readily accomplished by the method just described. Since the stabilized current depends upon the characteristics of the initial amplifier tube, it is necessary to employ a galvanometer and photo-cell arrangement to take care of variations in these characteristics.

The grid voltage on the initial amplifier tube which causes normal stabilization is determined by the plate current which must flow. One can therefore change the stabilized voltage by shunting the initial tube with a resistance. The photo-cell is so arranged that, depending upon which element receives the greater illumination, a condenser is charged or discharged. The voltage across this condenser is applied to the grid of a tube which acts as a variable resistance shunting the initial amplifier tube. In operation, therefore, as the stabilized magnet current drifts below its normal value, due to a change in tube characteristics, the galvanometer illuminates one element of the photo-cell more strongly than the other. The resulting change in grid voltage on the following vacuum tube changes the stabilization point on the initial amplifier tube so that the magnet current is returned to its original value. Here, as before, a time lag is unavoidable due to the slow response of the galvanometer, and hunting will be observed. Since the gain must be very high, as this is the ultimate stabilization standard, in order to reduce the amplitude of hunting compensation must take place very slowly in comparison with the time lag. Due to this slow response, sudden changes in filament heating power and plate potential on the first tubes still cause fluctuations in magnet current. These fluctuations are appreciable in this case because of the relatively low stabilized voltages which control the grid of the initial amplifier tube. A six-volt storage battery supplying the filament power for the first four tubes and a 45-volt "B" battery supplying the plate voltage on the initial tube eliminate this difficulty. The galvanometer and photo-cell arrangement is still necessary to take care of slow drifts due to heating and aging of the vacuum tubes.

The details of the stabilizing circuit depend to some extent upon the particular magnet. The complete circuit which has been adopted for the Michigan beta-ray spectrometer is shown in Figs. 3 and 4. The performance of this stabilizer has been very satisfactory. On a typical test the current was observed to vary by less than one part in 50,000 over a period of several hours. It is quite probable that even this amount of drift could be reduced by using better resistors in series with the magnet for furnishing the galvanometer e.m.f., but since the observed constancy was more than adequate for the intended purpose no effort has been made to improve the performance. Instantaneous fluctuations in the 220-volt line of 50 volts did not cause a noticeable fluctuation in the stabilized magnet current. Furthermore the stabilizer is very convenient to use, as the magnet current may be shifted to a new stabilized value in about 10 seconds.