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An Azimuth-Stabililzed Balloon Platform

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SPANO — AN AZIMUTH-STABILIZED BALLOON PLATFORM

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By

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A Thesis

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MASTER OF SCIENCE

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CHAPTER I

THE PROBLEM

Introduction

In the study of the Zodiacal Light, an interesting task is the determination of the intensity and the position of this glow on the celestial sphere. The problem of photographing this phenomenon from the earth's surface has been hampered generally by the inevitable presence of the atmosphere between the camera and the object. However, it is expected that at the height of some thirty kilometers above the earth, the atmospheric haze will be reduced enough so that pictures of the zodiacal region may be obtained without significant absorption. To accomplish this, it is necessary to keep the balloon-borne camera pointed in the desired direction while the photograph is taken.

It is the purpose of this thesis to design a mechanism which maintains proper orientation of the camera.

CHAPTER II

DESCRIPTION OF APPARATUS

General

The object of the servo-mechanism is to maintain a small platform held aloft by balloons in a given azimuthal direction. The platform (see Figure 1) is attached to the balloon suspension cable by a ball bearing in order to minimize any rotation of the platform whenever the balloons themselves rotate. The sensitive element of the servo-mechanism is a bar magnet which, when floated on an appropriate liquid, tends to point toward magnetic north. Along the axis of rotation of the magnet is a pin which mechanically couples the magnet to the shaft of a low-torque potentiometer. In this way, the shaft follows the bar magnet no matter how much the body of the potentiometer itself rotates. If the platform to which the potentiometer is rigidly attached rotates, an error voltage is developed which is applied to a difference amplifier. The output of this amplifier controls a small d.c. servo motor. This motor, bolted to the base of the platform, turns a worm gear which is attached through a shaft to the long arms of the counter mass. Then, as the motor turns this inertial mass in one direction, the platform turns in the opposite direction with an angular velocity such that the angular momentum of the entire system is conserved. The sign of the error voltage controls the motor in such a direction as to return the

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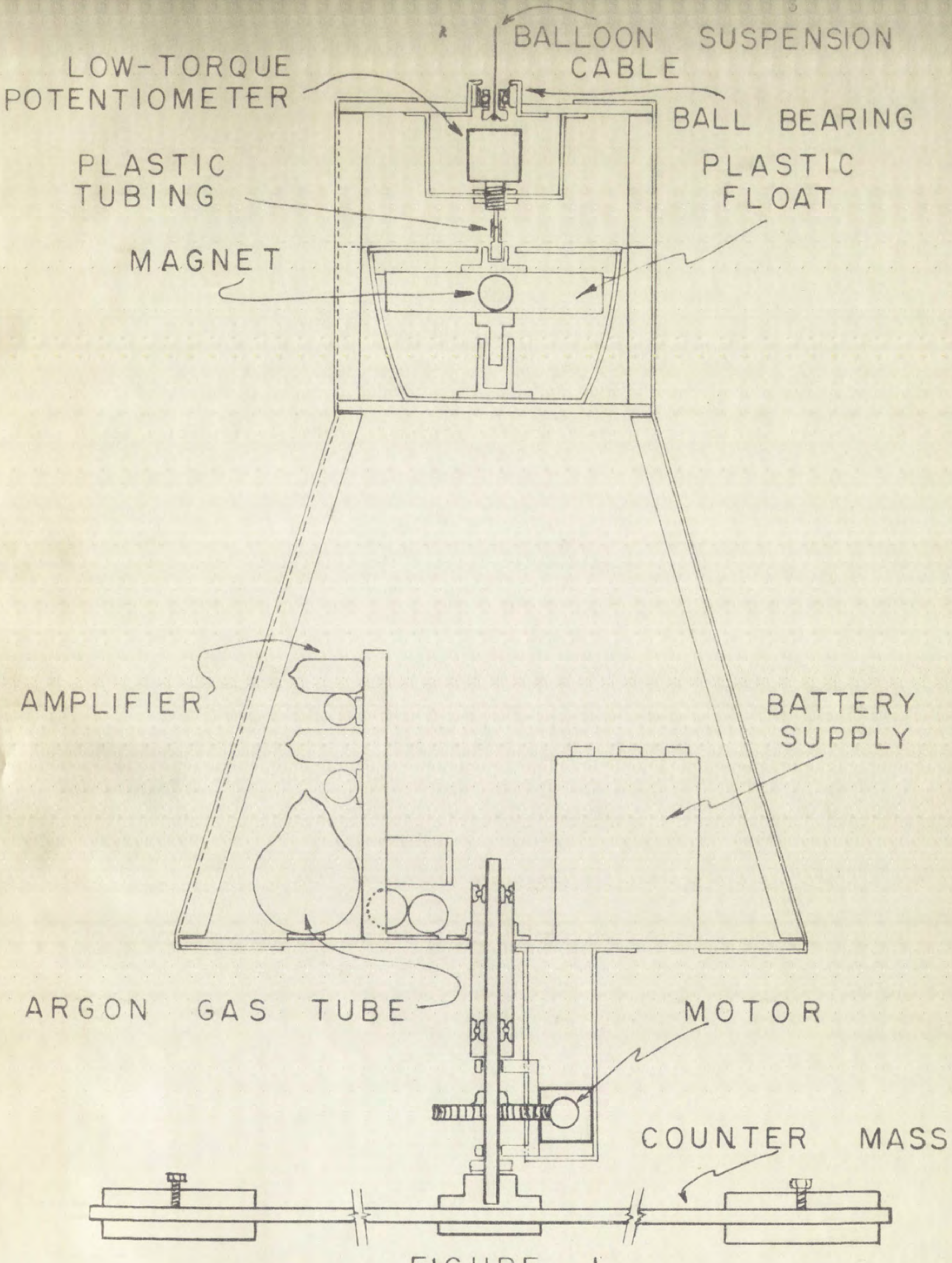

FIGURE I
BALLOON PLATFORM

platform to the original orientation.

Relay control of the d.c. motor

One of the requirements of the present problem is that the weight of the device carried by the balloons be kept as small as possible. To satisfy this condition, it is desirable that the servo motor be powered directly by battery. This is achieved by the use of relay control of a permanent magnet d.c. motor. A general treatment of this subject is given by Greenwood, et al.[1].

It is possible to have abrupt on-off control whereby the potential applied to the motor is constant, but with a polarity depending on the sign of the error signal. For example, in Figure 2, consider that the error signal to the output tubes T_3 and T_4 of the difference amplifier is such that T_3 conducts and T_4 does not. For this case, contact B is open when contact A of the relay is closed, and a constant potential is applied to the motor in the direction shown until contact A opens again. In the case of an error signal of opposite sign, contact B would be closed and the current would flow through the motor in the opposite direction. This on-off type of control results in the mechanism overshooting its zero position, introducing an error

1. I. Greenwood, J. Holdam, and D. MacRae, Electronic Instruments, Radiation Laboratory Series, Vol. 21 (New York, McGraw Hill, 1948), Sec. 12-20.

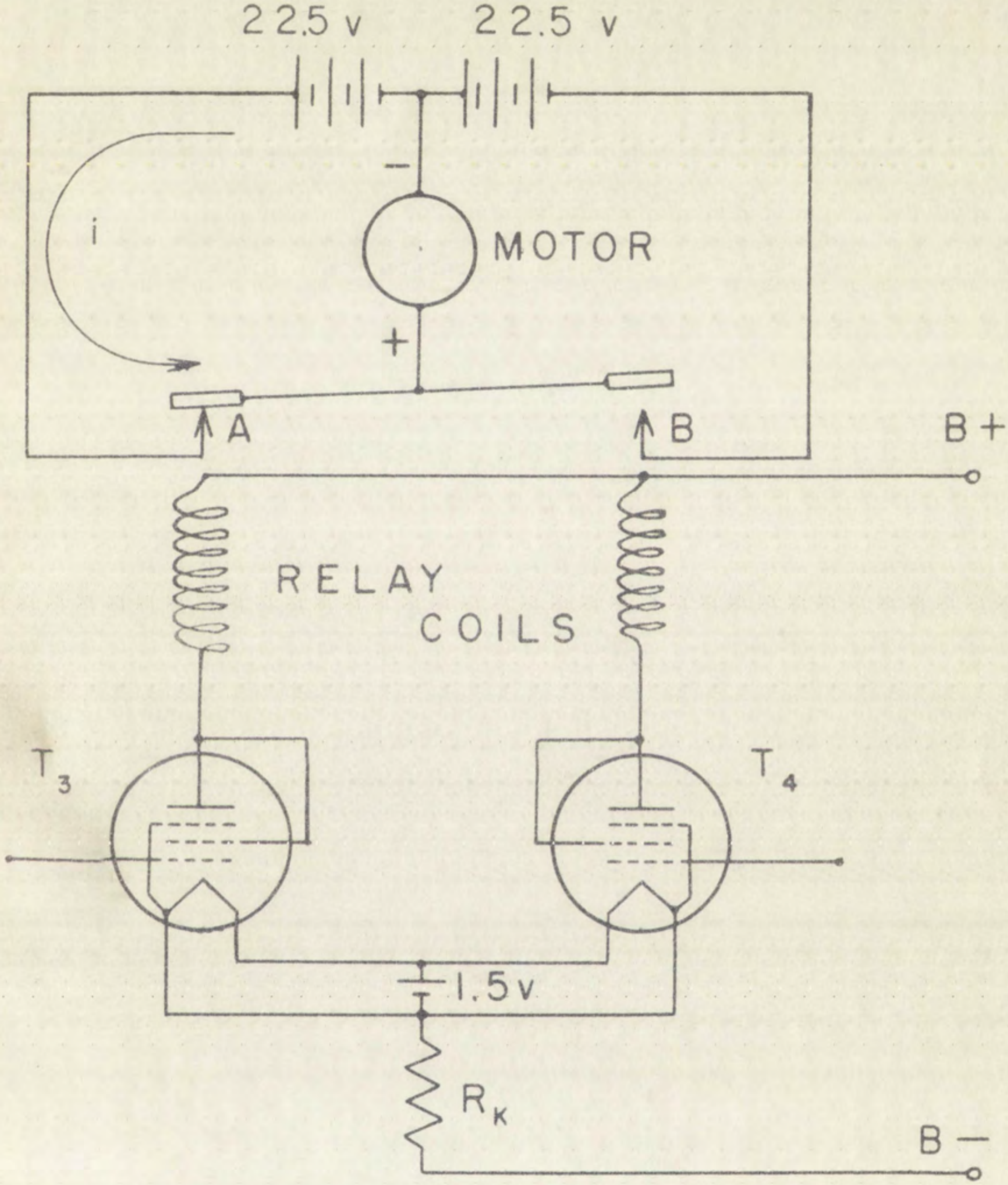

FIGURE 2

RELAY CONTROL OF A D.C. MOTOR

of opposite sign which reverses the motor and directs the mechanism toward the zero position, whereupon it overshoots again. This "hunting" characteristic cannot be tolerated for the present device and can be minimized in the following way. If the relay is allowed to vibrate with a frequency which is too high for the motor to follow, then the motor remains at rest. Now, if a d.c. error signal is superimposed on the relay, one contact will remain closed a greater fraction of the time than the other contact, approximately in proportion to the error signal. Thus, relatively smooth speed control of the motor is achieved.

The oscillating relay causes pulses of current of opposite sign through the motor even when the error signal vanishes. This waste of power is quite small and entirely permissible, since the pulse length is small and becomes smaller for higher frequencies due to the inertia of the armature of the relay. At very high frequencies, the amplitude of oscillation of the relay becomes too small to prevent hunting. An optimum frequency can be found experimentally.

Relay and motor

Smooth control of the motor is achieved through relay oscillations. Unless adequate precautions are taken to eliminate contact sparking, pitting or welding of the points may result. A suitable means of overcoming this problem requires a simple R-C circuit across each contact.

The relay is vibrated electronically in a simple and economical manner using a small Argon gas tube as a relaxation oscillator. The circuit is shown in Figure 3. The output sawtooth signal is impressed on the control grid of one of the amplifier tubes through a coupling capacitor as shown in the complete circuit diagram of Figure 4. Another amplifier tube can be used between the oscillator and control grid of T_2 to increase the signal and so allow more leeway in varying the signal strength. This was tried, but the greater power drain was considered undesirable.

The small permanent magnet motor used provides enough torque to turn the counter mass with 22½ volts across it, drawing an average current of 80 milliamperes.

Difference amplifier

A complete discussion of the subject of differential amplifiers can be found in the book by Valley and Wallman.[2] A simplified analysis of the particular symmetrical arrangement used in this work is given here. The basic circuit element shown in Figure 5 has the property that when input signals of potential e_1 and e_2 are applied to the grids, the difference of the output

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[2] G. E. Valley and Henry Wallman, Vacuum Tube Amplifiers, Radiation Laboratory Series Vol. 18 (New York, McGraw Hill, 1948), Sec. 11-10.

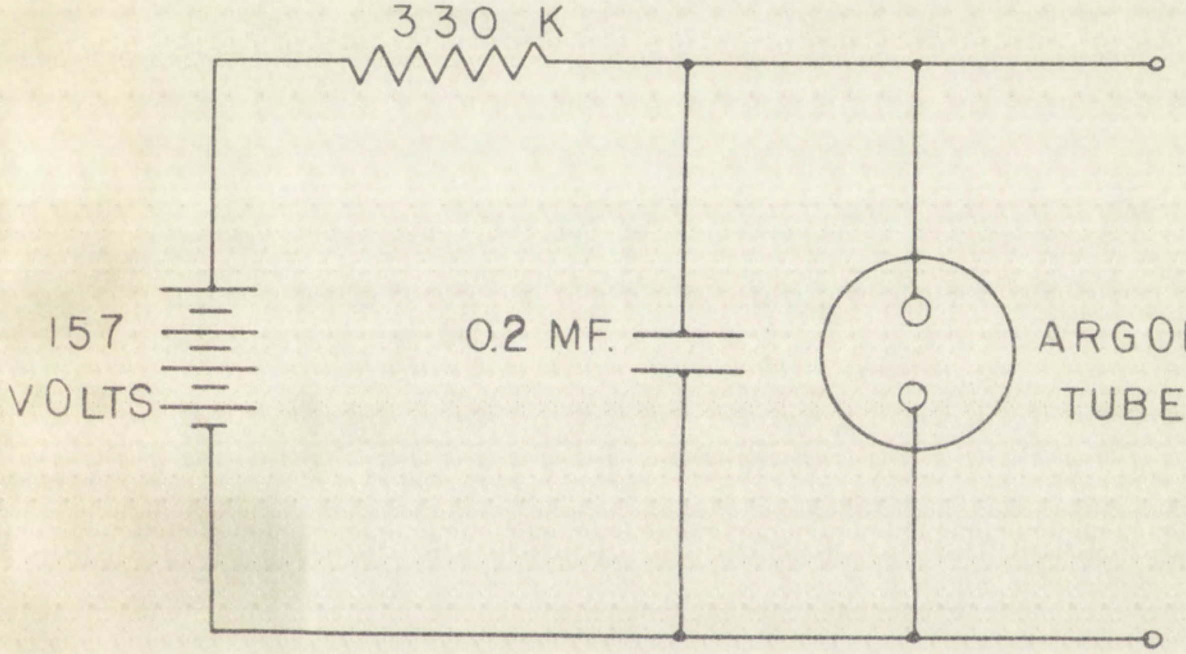

FIGURE 3

ARGON TUBE OSCILLATOR

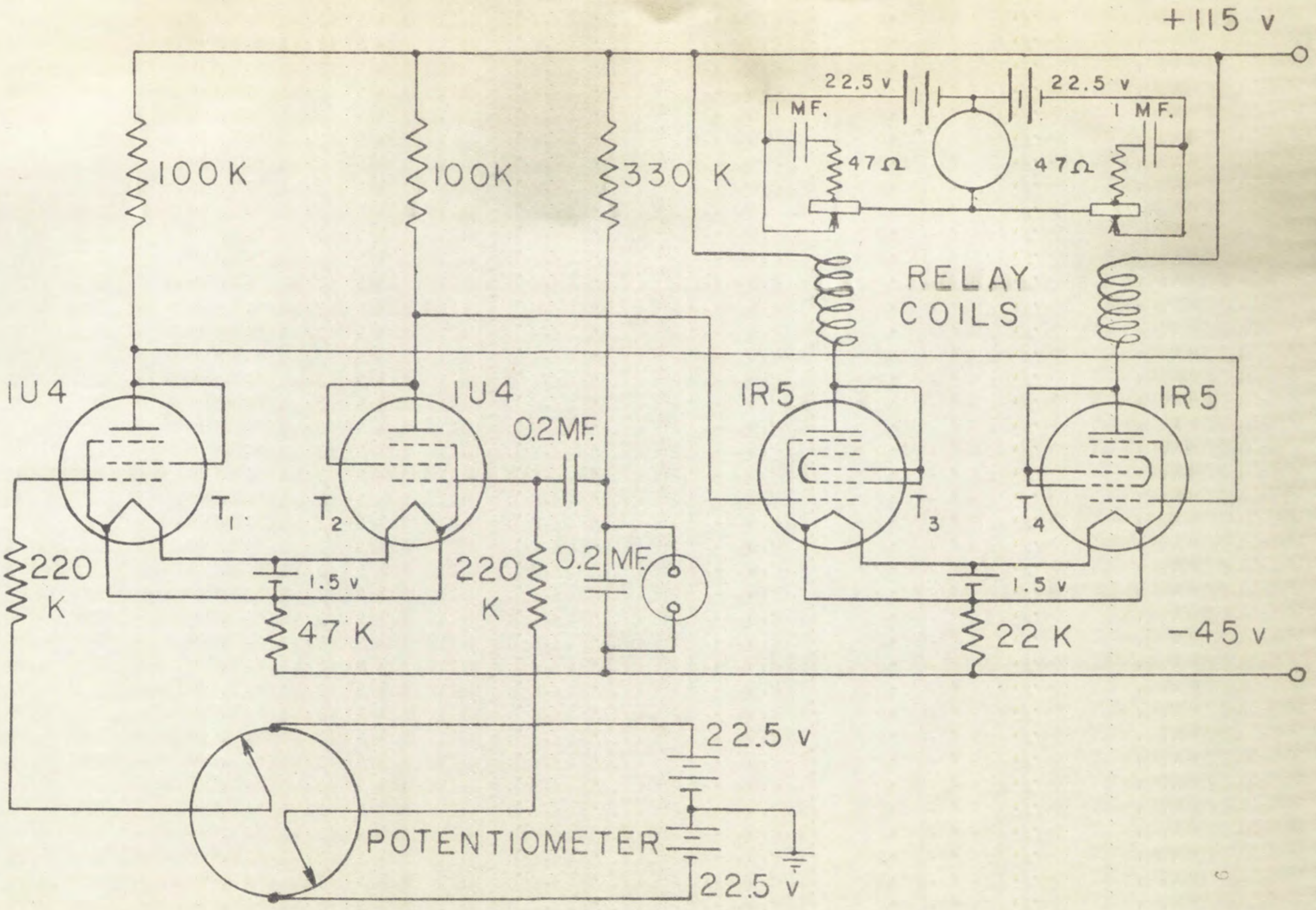

FIGURE 4

COMPLETE SERVO CIRCUIT

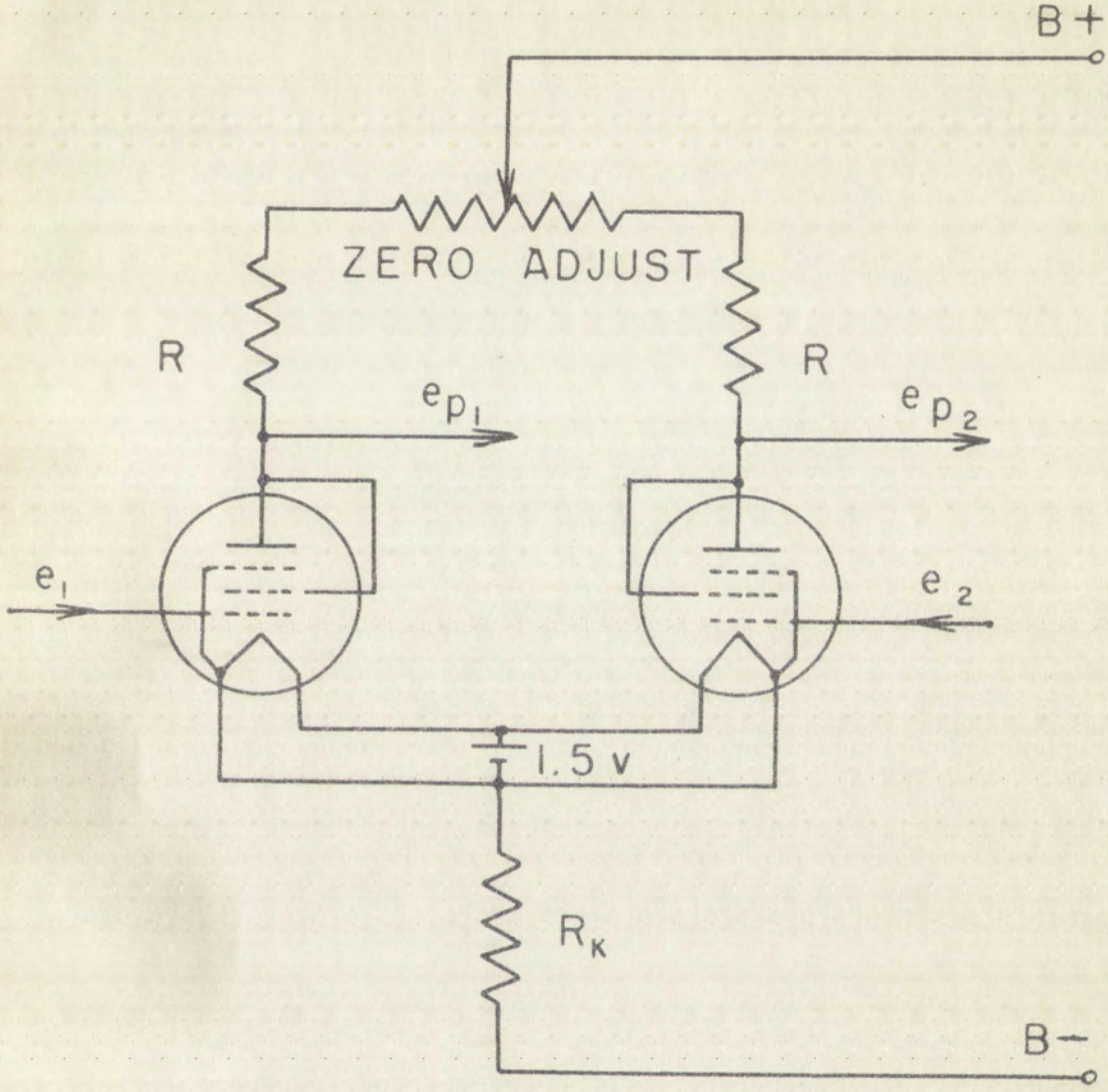

FIGURE 5

SYMMETRICAL DIFFERENCE AMPLIFIER

STAGE

potentials, $(e_{p1} - e_{p}2)$, at the plates is approximately proportional to the difference of the input potential, $(e_1 - e_2)$ Qualitatively, this can be seen in the following way. The common cathode resistor, R_k, for the two tubes T_1 and T_2 acts as a constant current element, provided the excursions of the cathode potential are small compared to the potential across R_k. This constant current is shared by T_1 and T_2. If a signal is applied to grid 1, for example, the current change produced in T_2 is then equal and opposite to that produced in T_1. The zero control shown allows matching of the tubes. For the case at hand, this is not necessary since differences in the tubes result merely in the potentiometer finding a new position for zero error signal.

The feature of connecting the cathodes of the difference amplifier not to a fixed potential but to the common cathode resistor also allows stabilization of the circuit against heater voltage variations. Were the heater voltage to fall, tending to decrease the current through the tube, the potential drop across R_k would also fall. This would decrease the grid bias and the current would increase proportionally, compensating for heater voltage variation.

As the complete circuit diagram in Figure 4 shows, the input stage consists of two 1U4 pentodes in triode connection, while the output power stage consists of two 1R5 pentagrid tubes in triode connection. The two coils of the differential relay act as plate

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In the complete circuit diagram in Figure [illegible] shown, the input stage consists of two [illegible] pentodes in triode connection, while the output power stage consists of two [illegible] pentodes [illegible] in triode connection. The two sides of the differential being [illegible] alike.

resistors for the 1R5 tubes. An economic consideration in the selection of tubes is that the filament current drawn be small enough to permit the use of small 1.5 volt A-batteries.

Microtorque potentiometer

The small Electro-Mec potentiometer, type 1395, weighs 0.8 ounces and has a shaft torque of about 0.015 oz.in. A potential difference of 45 volts is applied across the potentiometer resulting in a current of 0.9 milliamperes in each branch.

It is important that no excessive strain be placed on the delicate shaft of the potentiometer. For this reason, a non-rigid mechanical coupling to the shaft pin of the magnet float is made by means of a small length of plastic tubing (see Figure 1). Unless the two shaft ends are close together, some twisting of the plastic tubing results before the potentiometer shaft itself rotates, causing delayed action and servo dead space. To eliminate this, the free length of tubing between the ends of the potentiometer shaft and the float shaft must be made as small as possible.

Floating bar magnet

The bar magnet of Alnico steel is encased in a closed plastic container which is floated in a bowl filled with ethylene glycol. This liquid is tentatively chosen because of its low freezing point

and because of its relatively high specific gravity of 1.25, which enables the heavy magnet and container to float. A small lucite pin glued to the bottom of the round float is used to center it within the bowl; on top of the float a lucite shaft permits small vertical displacements while mechanically coupling the float to the shaft of the potentiometer. In this way, no excessive strain due to vertical movements of the magnet is placed on the delicate shaft.

Platform construction

The platform is made of composition wood bolted to a framework of right angle aluminum channel. Steel bolts and nuts are avoided to eliminate any perturbing effects on the magnet due to the presence of iron in the locality. For the same reason, the motor is placed at a distance of forty centimeters from the magnet.

CHAPTER III

PERFORMANCE AND CONCLUSION

The Bar Magnet

In general, servo mechanisms have the property that increased sensitivity brings with it increased hunting, and the problem becomes one of first assigning a given desired sensitivity and then devising methods to decrease the hunting. The final model of the device will need a sensitivity such that if an error angle of the order of one half of one degree is developed, the servo reacts to correct that error. In this respect, the present model worked very poorly, chiefly because the magnet used had too small a magnetic moment.

A calculation is now made to indicate how strong a magnet is needed to attain a sensitivity of one half of one degree using the described potentiometer. In order to turn the shaft, the magnetic moment $\vec{M}$ of the magnet interacting with the earth's field, $\vec{B}$, must develop a torque greater than the given shaft torque of magnitude 0.015 oz. in. The torque, $\vec{T}$, on the magnet is given by

$$|\vec{T}| = |\vec{M} \times \vec{B}| = M\,B\,\sin\theta$$

where θ is the angle between the earth's field and the direction of the magnetic moment of the magnet. It is desired that θ be about one half degree. Using 0.24 gauss for the horizontal component of the earth's field, it is seen that a magnetic moment of

$$M = \frac{T}{B\sin\theta} = \frac{0.015}{(0.24)(0.0087)}\ \frac{\text{oz. in.}}{\text{gauss}}$$

$$M = 7.4\ \frac{\text{oz. in.}}{\text{gauss}}$$

is necessary.

The magnet float was tested in the following way. It was placed in a bowl filled with ethylene glycol large enough so that the float could move freely without hitting the edge of the bowl. Under these conditions the magnet turned quickly and easily toward north in critically damped fashion. However, when the float was coupled to the shaft of the potentiometer the magnet could only turn to about 20 degrees of magnetic north, indicating a magnetic moment of

$$M' = \frac{0.015}{(0.24)(0.34)} = 0.18 \ \frac{\text{oz. in.}}{\text{gauss}} ;$$

or about forty times smaller than the calculated required value.

Behavior of final servo loop

Initially, a preliminary servo loop was created in which the motor rotated a worm gear to which the potentiometer shaft was directly coupled. Tests of this loop permitted adjustments of some of the circuit parameters for the purpose of obtaining what seemed to be a reasonable compromise between sensitivity and hunting. The characteristics of this arrangement were highly satisfactory. When the potentiometer was rotated slowly, the servo reacted quickly enough to enable the shaft to follow smoothly and maintain its original position relative to the body of the potentiometer, so that both body and shaft seemed to rotate together. When the potentiometer was rotated suddenly, the shaft followed after a short delay, reaching its initial relative position with little or no hunting.

The magnet float was tested in the following way. It was placed in a bowl filled with ethylene glycol large enough so that the float could move freely without disturbing the sides of the bowl. Under these conditions the magnet turned quietly and easily from east through [illegible] critically damped fashion. However, when the float was coupled to the shaft of the potentiometer the magnet would only turn to within 20 degrees of magnetic north, indicating a magnetic moment of

$$\frac{[illegible]}{[illegible]} = \frac{0.016}{(0.33)(0.36)} = 0.13 \text{ cm. gm.}$$

or about forty times smaller than the calculated required value.

<u>Behavior of fluxgate servo loop</u>

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In contrast to the first arrangement, the operation of the final loop was not satisfactory for a number of reasons. Among these was the fact that the magnet was totally inadequate for the potentiometer used. As shown above, for a sensitivity of half a degree, a magnet was needed with a magnetic moment forty times larger than the present one.

Unless a bar magnet can be obtained with an increased magnetic moment per unit volume, the mass of the magnet will have to be increased a factor of forty to yield the required moment. In view of this, it may be necessary to devise a method other than the potentiometer method for sensing the error angle. This might be done by means of photoelectric control at a sacrifice of simplicity.

The particular plastic bowl used to float the magnet was not as large as might be desired. This, together with the appreciable viscosity of ethylene glycol, tended to make the motion of the magnet somewhat sluggish.

It was noticed that the platform tended to follow the twisting motion of the suspension cable. Use of a better ball bearing would help to correct this condition.

In conclusion, it may be said that the work thus far indicates that the idea of a magnetically stabilized balloon platform is practicable.

IV. ACKNOWLEDGEMENT

I wish to thank Professor V. H. Regener for suggesting the problem and for his guidance and help.

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