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A METHOD OF MEASURING PHASE RELATIONS IN A POSITIONAL SERVOMECHANISM

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ABSTRACT

A common method of testing servomechanisms is to measure phase and attenuation over a range of input frequencies. Difficulty is often experienced in measuring phase angles because of distortion of the output waveform. This report describes a method by which phase angles may be measured, when the output is non-sinusoidal, with the addition of only a negligible load to the servo output. The method entails the use of a light beam reflected by a mirror attached to the output shaft of the servomechanism. This light beam falls on a phototube twice every cycle, and indicates the phase relationship between the output and input of the servomechanism on a cathode-ray oscilloscope. In addition to describing the procedure for obtaining frequency-versus-phase curves the report also gives details of the sine-wave generator used.

A METHOD OF MEASURING PHASE RELATIONS IN A POSITIONAL SERVOMECHANISM

INTRODUCTION

The performance of a servomechanism is analysed commonly by measuring either its sinusoidal or transient response. The sinusoidal response characteristics are particularly valuable as a means of checking the theoretical design of a servomechanism. Such characteristics are obtained by causing the input quantity to vary, or appear to vary in a sinusoidal manner. A comparison of the input and output variations then yields the sinusoidal response.

In a servomechanism having linear components, the output will follow a sinusoidal input signal. However, it will change in both phase and amplitude as the frequency is varied. It is this change in phase and amplitude of the output with respect to the input which provides useful information for the designer.[1]

The apparatus described in this report was devised to provide a relatively simple method of measuring the phase relationship between input and output during a closed-loop sinusoidal test. Previous methods of measuring this quantity have entailed either the use of special apparatus[2,3] or use of a cathode-ray oscilloscope. The latter method is simple and consists of comparing the phase of two waveforms generated by input and output selsyns. Actual measurement of phase is accomplished by obtaining Lissajous figures on the cathode-ray oscilloscope. An important disadvantage of such methods is that the form of the Lissajous figure depends upon the waveform of the voltage generated by the output selsyn. If this waveform is not exactly sinusoidal, the correct figure is not obtained and measurement of phase becomes almost impossible.

THEORY OF THE PHOTOELECTRIC METHOD

This method accomplishes measurement of phase by comparing the node of the output motion with the node of a waveform of known phase. As in common practice, a sinusoidal error signal is inserted in the servo loop to simulate a sinusoidal variation of the input quantity. Information concerning the position of the output shaft is conveyed by means of a light beam which falls upon a phototube at the instant when the output shaft passes its center position. The phase shift is measured by comparing, on a double-beam oscilloscope, the input of the phototube and a sinusoidally varying voltage whose phase can be varied and measured accurately with respect to the input signal. This variable phase voltage is produced by means of a conventional sine-wave generator.

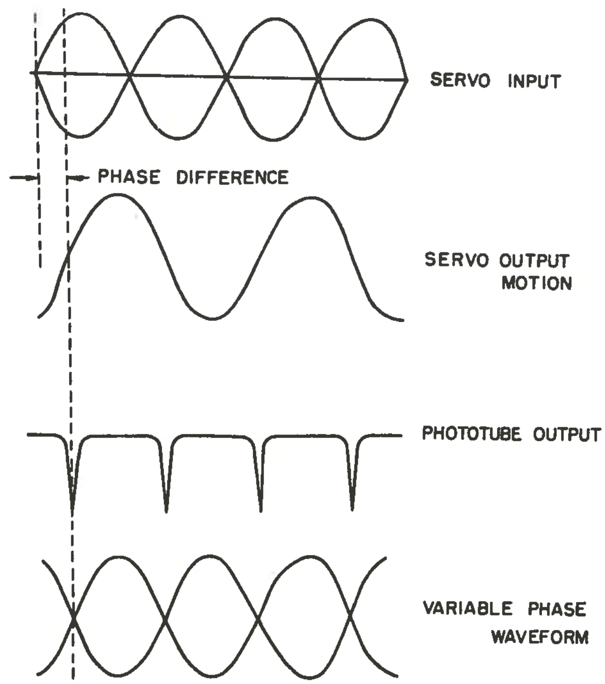

FIGURE 1. WAVEFORMS

Waveforms illustrating the mode of operation are shown in Fig. 1. If the servomechanism were perfect, the output shaft would be in its center position at the instant when the input signal was zero. In practice, the output motion lags behind the input, and as a result, the phototube pulses do not coincide with the input waveform nodes. By displaying the phototube output waveform and the variable phase waveform on a double-beam oscilloscope, the latter may be delayed in phase until its nodes coincide with the phototube pulses. The actual phase difference between input and output may then be read directly from a calibrated dial on the sine-wave generator.

DESCRIPTION OF APPARATUS

A diagram illustrating the general layout of apparatus is shown in Fig. 2. The projector consists of a 10-watt 6-volt lamp whose output is concentrated by means of a convex lens. The lamp is operated from a 6.3-volt 60-cycle source. Because of the brevity of the period during which light actually falls on the phototube, lamp flicker due to the a-c excitation has no effect on the phototube output. The projector light beam is reflected by a rectangular plate mirror, approximately ½ inch by 1 inch, which is cemented to the servo output shaft. The light beam is detected by means of a type-929 phototube which is contained in a cylinder of copper having a narrow longitudinal slot along one side. This cylinder acts as both an electrical and a light shield.

The phototube amplifier is a single-stage pentode circuit employing a type-6AH6 tube. This circuit is shown in Fig. 3. Because of the high gain of the amplifier and the small signal being amplified, care must be taken to prevent pickup from external circuits. For this reason, the phototube is connected to the amplifier through a shielded cable, and the cylindrical phototube shield is grounded.

The projector, phototube, and amplifier are all mounted on a slotted plate. The projector and phototube are mounted on brackets which enable them to be moved in the slots. This facilitates the setting up of the optical system to give the most satisfactory results.

MEASUREMENT PROCEDURE

The procedure for obtaining a phase-versus-frequency curve for a typical positional servomechanism is described below. The circuit diagram is shown in Fig. 4.

1) With zero input from the sine-wave generator, the input shaft is rotated until the reflected light beam falls approximately on the slot of the phototube.

2) An input signal is fed into the servomechanism from the sine-wave generator at some convenient frequency. This causes the light beam to sweep back and forth across the slot. By rotating the servo input shaft, the center point of the light beam oscillation may be moved so as to coincide with the phototube slot. Thus the light beam now falls on the slot at exactly the instant when the servo output shaft passes through its center position. This condition is indicated on the oscilloscope in the following manner.

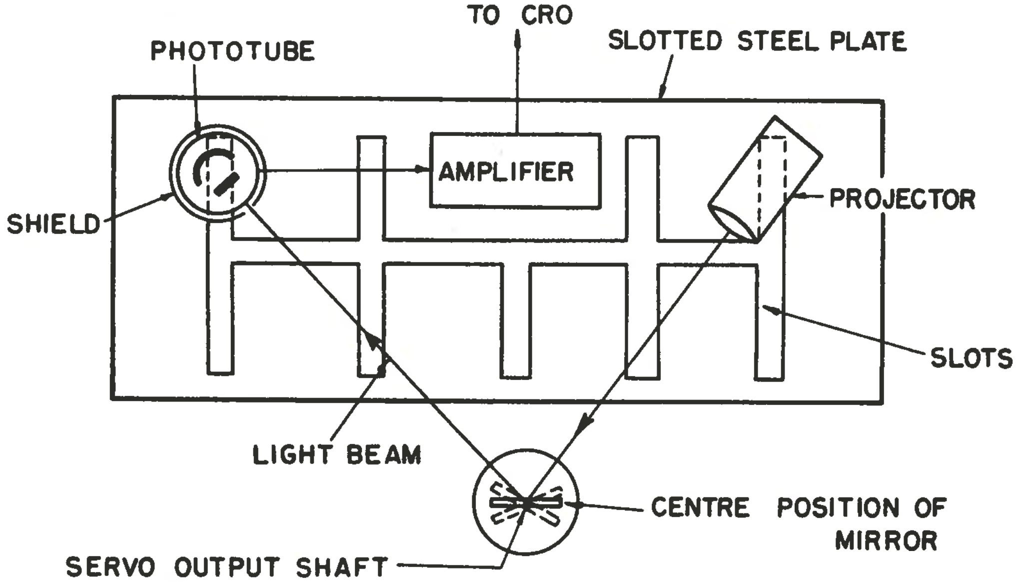

FIGURE 2.

GENERAL LAYOUT OF APPARATUS

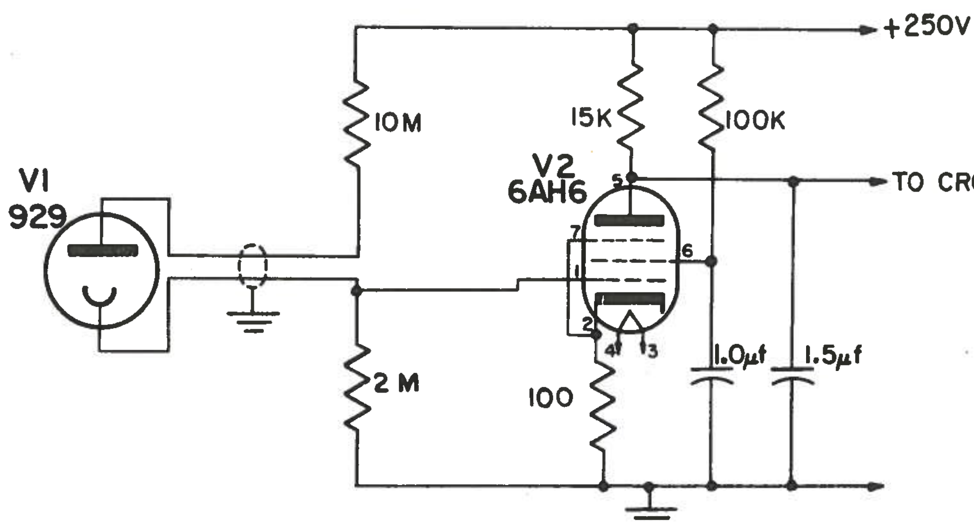

FIGURE 3

PHOTOTUBE AMPLIFIER.

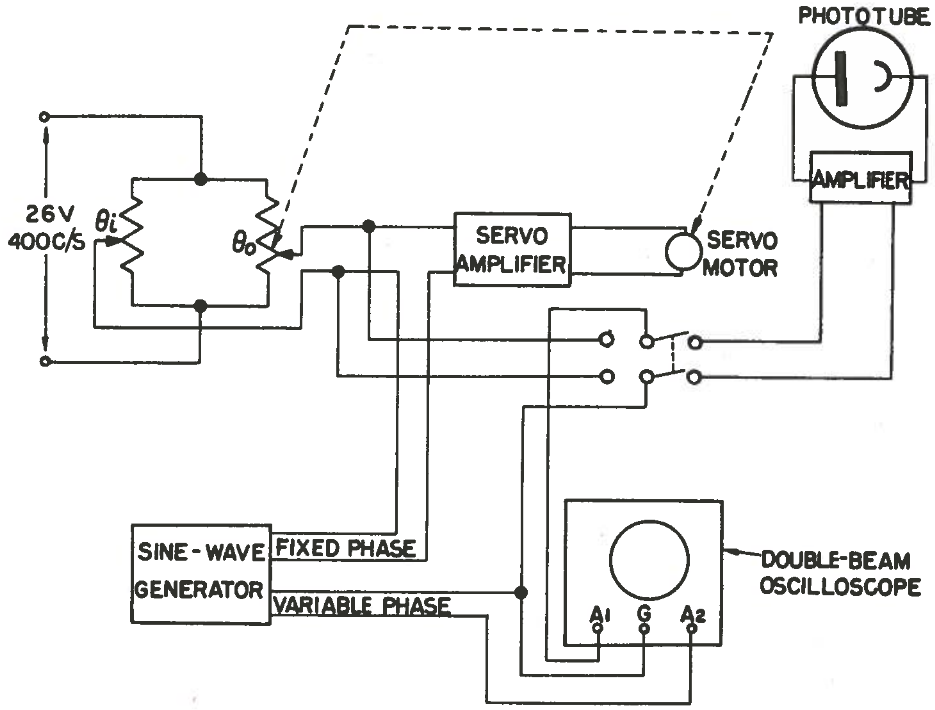

FIGURE 4

CIRCUIT FOR MEASUREMENT OF ANG $\frac{\theta_o}{\theta_i}$ AND $\left|\frac{\theta_o}{\theta_i}\right|$

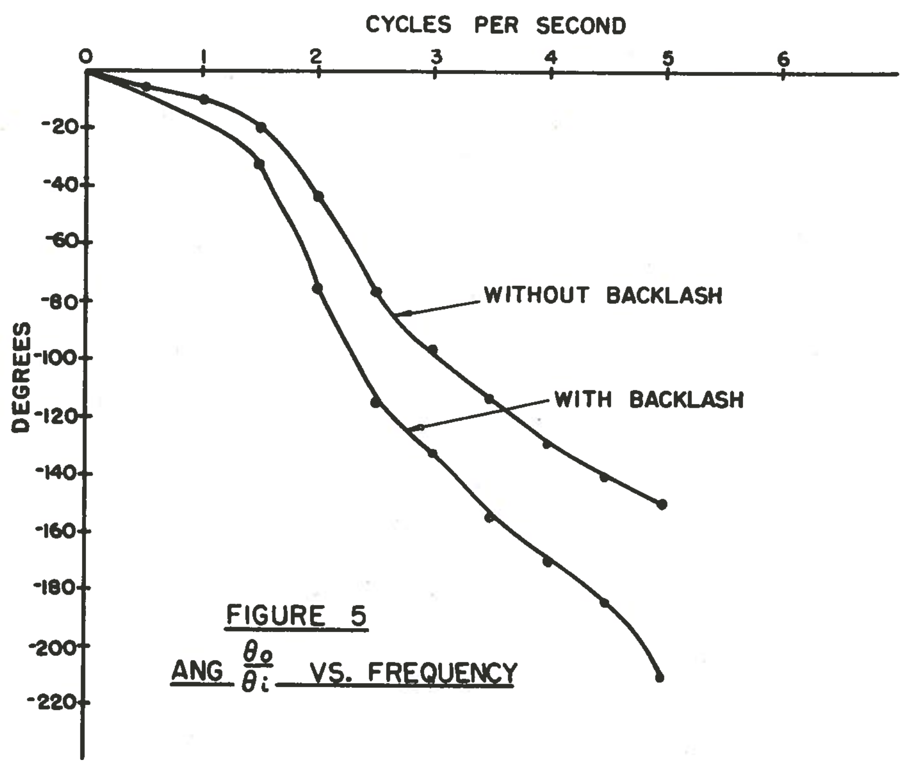

FIGURE 5

ANG $\frac{\theta_o}{\theta_i}$ VS. FREQUENCY

When the required condition as described above is obtained, the output pulses of the phototube are equally spaced in time. Therefore, if the oscilloscope sweep frequency is adjusted to be equal to the pulse frequency (or twice the sine-wave generator frequency), the resulting pattern on the screen will remain stationary. If the light beam oscillation is not exactly centered, the pattern will not be stationary. This method therefore enables the output shaft to be centered in a simple manner.

3) Readings of phase-versus-frequency are obtained by varying the phase of the variable-phase waveform until its nodes coincide with the phototube pulses for each value of input frequency. The phase difference may then be read from the calibrated dial on the sine-wave generator.

In the circuit shown in Fig. 4, provision is made for observing the servo output waveform on the oscilloscope. By measuring the amplitude of this waveform at each frequency, a curve of $\left|\frac{\theta o}{\theta i}\right|$ versus frequency may be obtained. This is a conventional method of obtaining such a curve and no additional apparatus or load on the servo is required to make such measurements.

DISCUSSION OF PHOTOELECTRIC METHOD

The main application of the method described in this report is in finding the phase relation between input and output for a positional servomechanism with a sinusoidal input. An important feature of the method is that the additional load placed on the servo when under test is negligible since the inertia of the mirror is very small.

A second valuable feature of the photoelectric method is that it may be used to test a servomechanism whose output is non-sinusoidal when its input is sinusoidal. Most servomechanisms are non-linear to a certain extent, and the difficulty experienced in obtaining satisfactory Lissajous figures on a cathode-ray oscilloscope for such servos has been mentioned. This method eliminates such difficulties and enables accurate measurements to be made.

With regard to the measurement of phase shift in a non-linear servo, it should be remembered that this apparatus yields only the phase shift between the input node and the instant when the output passes through zero. The response of a non-linear servo to a sinusoidal input will be a complex waveform containing a fundamental and harmonics. The fundamental will thus be shifted in phase with respect to the complex wave. This fact must be considered when interpreting the results obtained by the phototube method.

Only slight distortion of the output waveform is necessary to render the Lissajous figure method unusable. For such waveforms the method described in this report will yield accurate values for the phase shift between the input signal and the fundamental component of the output. For cases where greater distortion is present in the output waveform, this method will yield accurate values for the phase shift between input and output signals, but will not give values for the phase shift between the input signal and the fundamental component of the output. To obtain such values it would be necessary to make an analysis of the output waveform.

As an example of the applications which the photoelectric apparatus might have, phase curves for a positional servo, with and without backlash, where obtained. These are plotted in Fig. 5.

The apparatus could possibly be used to measure the open-loop sinusoidal response of a servo. However, drifting of the operating point of open-loop servos while under test is a serious handicap to successful measurement by this method, as with other methods of obtaining sinusoidal response.

The sensitivity of the photoelectric apparatus was found to be quite satisfactory for most applications. When testing servos by this method, it was estimated that the phase angle of the zero-crossing of the output quantity could be determined with a maximum error of approximately 3 degrees.

The frequency range over which the photoelectric method may be used is limited only by the small angle through which the light beam oscillates at high frequencies. Greater discrimination can be obtained by increasing the distance between the mirror and the phototube. Actual use of this apparatus has been made between the frequencies of 0 and 8 cps only, because of the frequency limitations of the servos under test.

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The author wishes to acknowledge the invaluable advice rendered by Mr. N.L. Kusters, Mr. D.M. Murray, and Mr. C.R. Clemence of the Radio and Electrical Engineering Division. Mr. Clemence also designed the sine-wave generator described in the Appendix.

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APPENDIX

DESCRIPTION OF SINE-WAVE GENERATOR

A circuit diagram of the sine-wave generator is shown in Fig. 6.

Frequency control is accomplished by means of a velocity servomechanism. The generated voltage-versus-speed characteristic of the d-c generator is linear. Thus, a meter measuring the generated voltage is calibrated directly in cycles per second.

Two output waveforms, one fixed in phase and the other variable, are produced by means of three resolvers connected as shown. The rotor of Resolver #3 is operated by means of a dial calibrated in degrees. Rotation of this dial varies the modulation phase of the waveform appearing at terminals A-A. Terminals B-B provide a fixed-phase waveform whose RMS value can be varied from 0 to 100 millivolts by means of a calibrated potentiometer. Terminals C-C provide a fixed phase waveform whose RMS value is 26 volts.

The frequency range available is from 0 to 32 cycles per second. The motor is coupled to the resolvers by means of a double pulley. This enables two frequency ranges, of 0 to 16 and 0 to 32 cps, to be obtained. In addition, the frequency meter has two ranges which may be selected by a switch, so that full-scale readings of 5, 10, 20, and 40 cps are available.

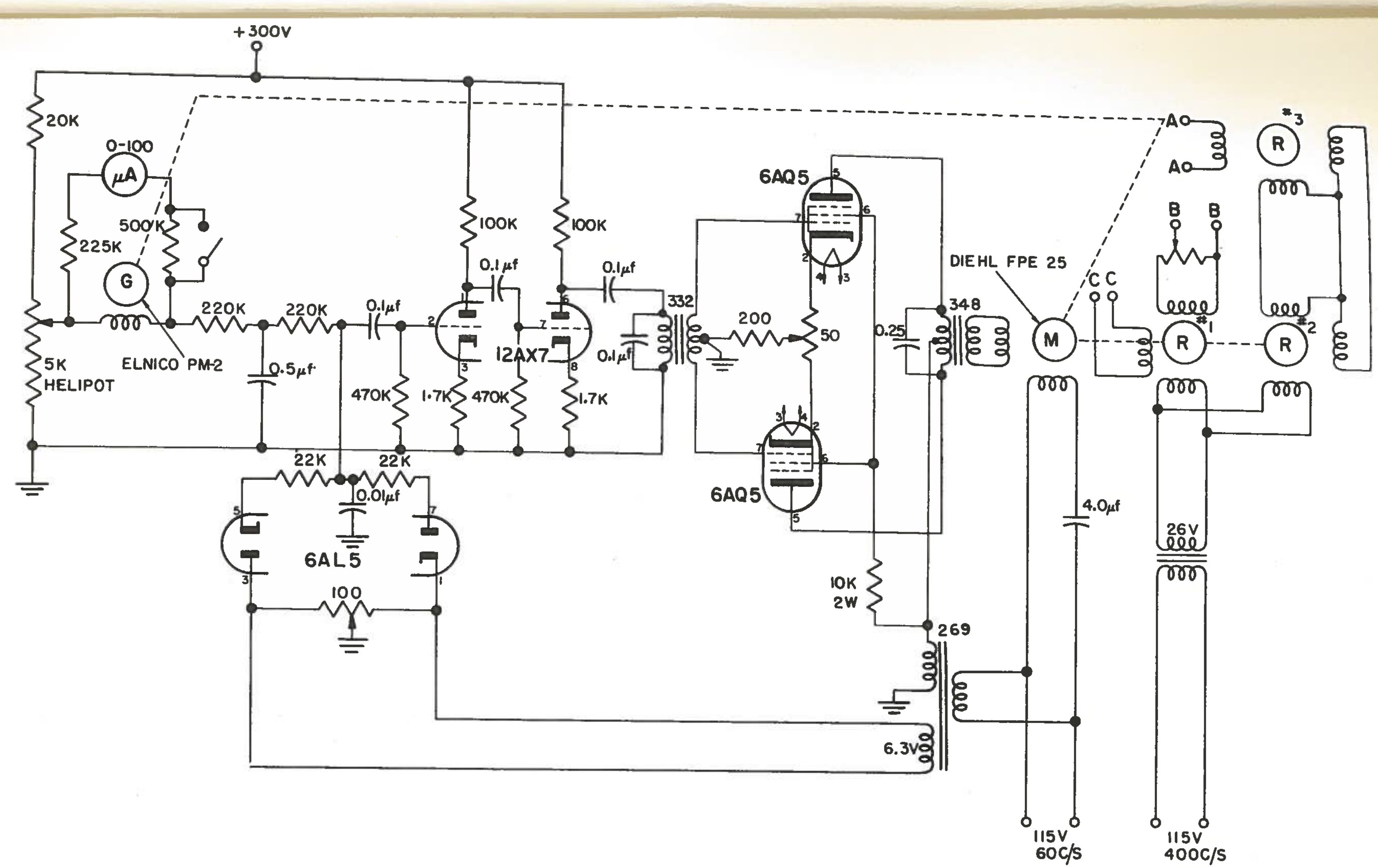

FIGURE 6
CIRCUIT DIAGRAM OF
SINE-WAVE GENERATOR