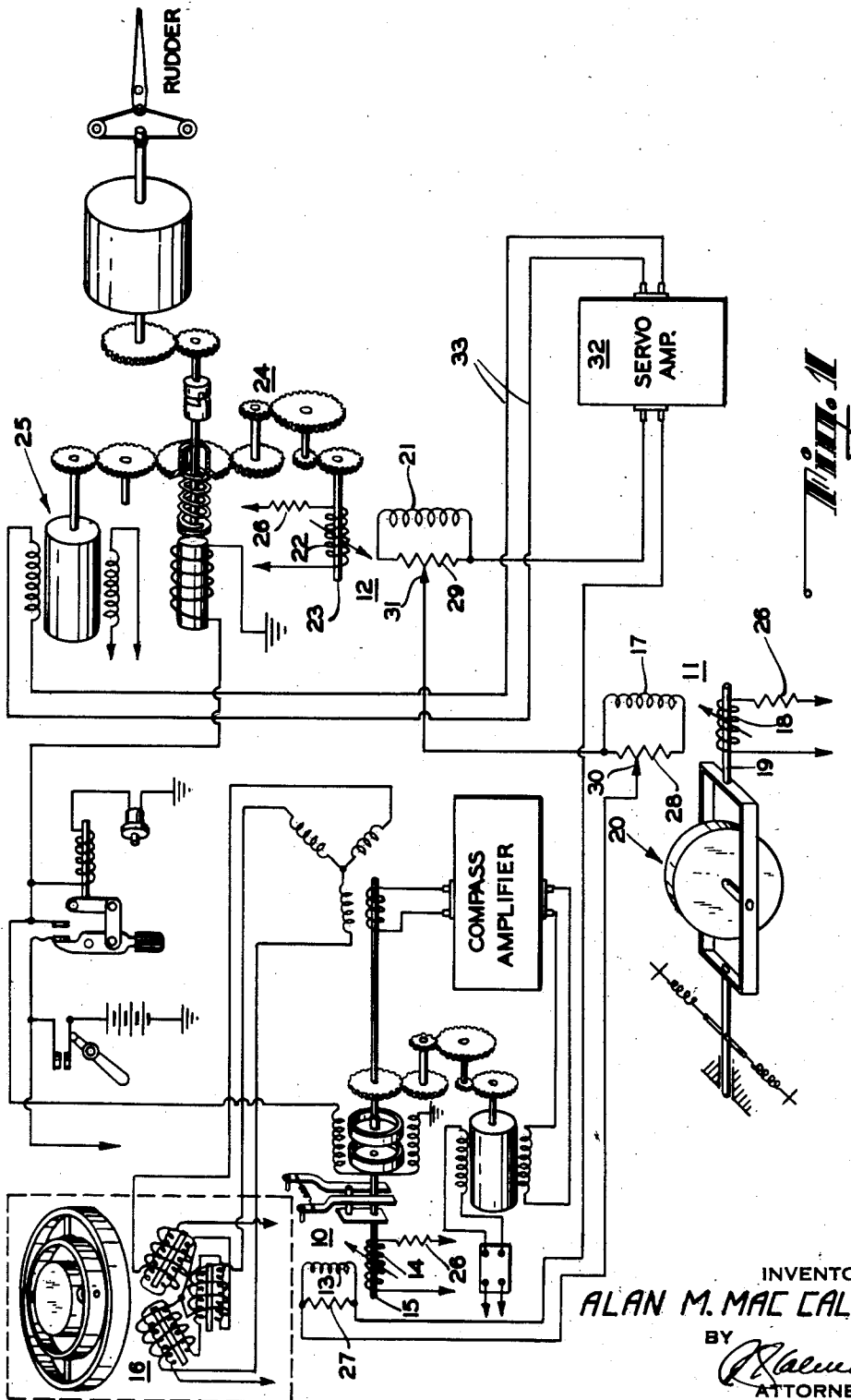


A. M. MacCALLUM
AUTOMATIC STEERING SYSTEM

AUTOMATIC STEERING SYSTEM

3 Sheets-Sheet 1



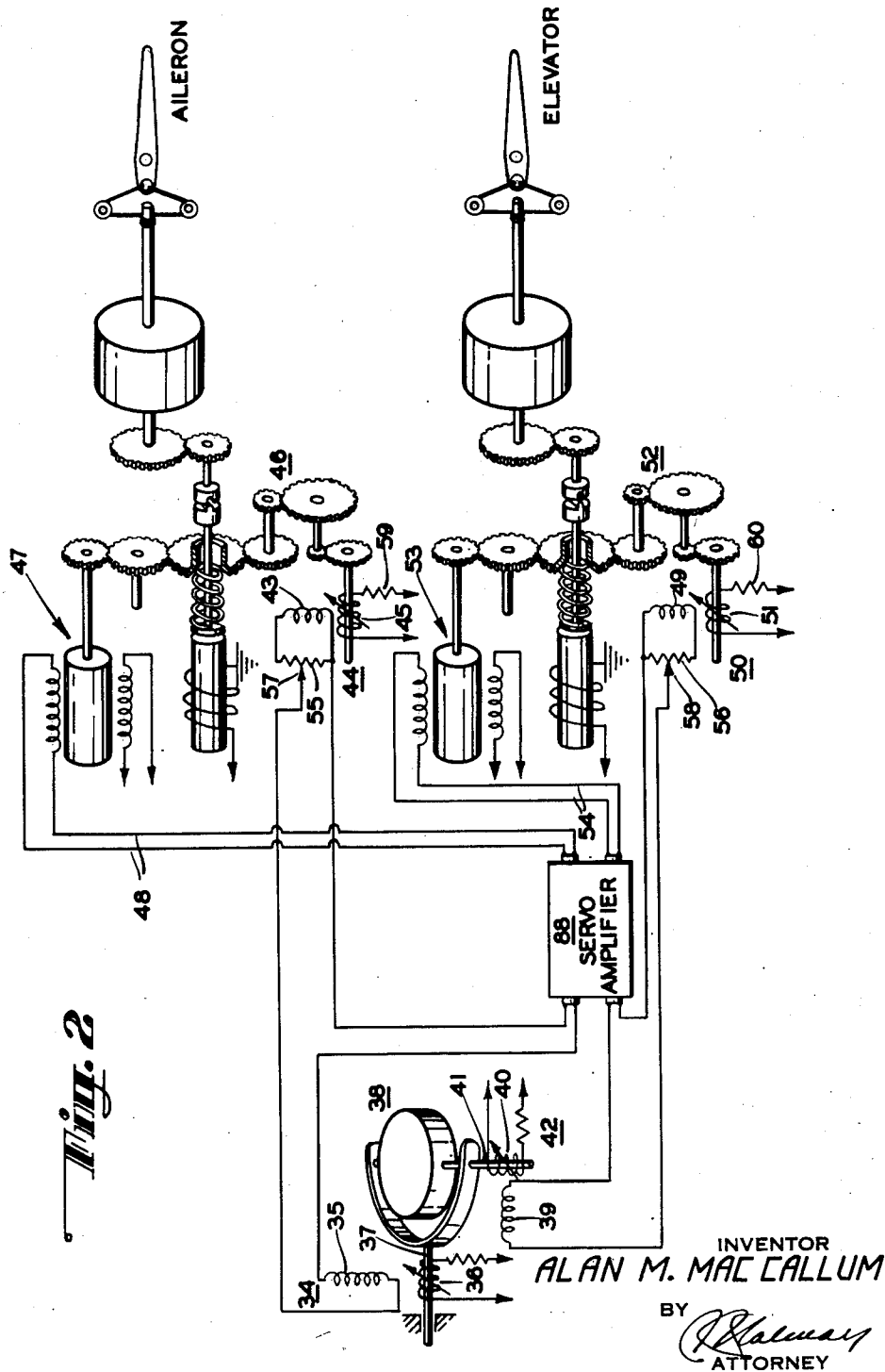
June 16, 1953

A. M. MacCALLUM
AUTOMATIC STEERING SYSTEM

2,642,554

Filed Jan. 23, 1947

3 Sheets-Sheet 2



June 16, 1953

A. M. MacCALLUM

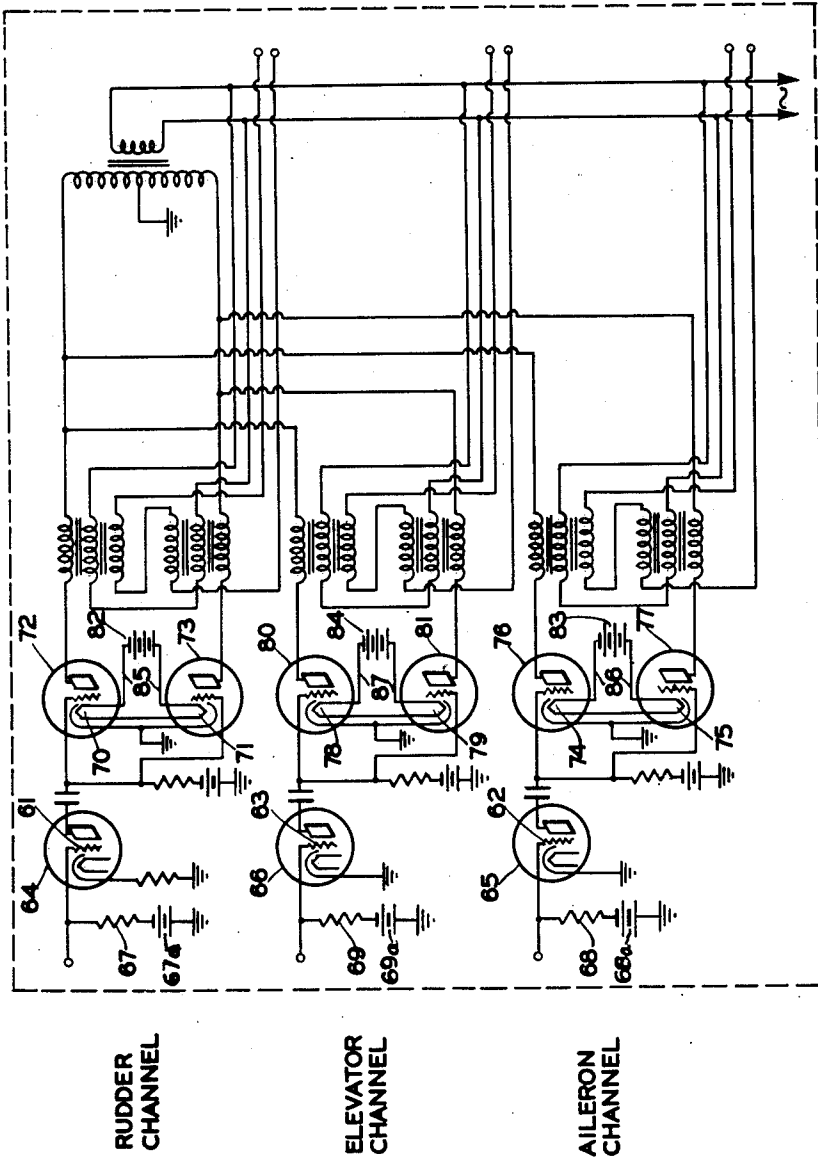
2,642,554

AUTOMATIC STEERING SYSTEM

Filed Jan. 23, 1947

3 Sheets-Sheet 3

Fig. 3



INVENTOR
ALAN M. MAC CALLUM

BY *Alan M. MacCallum*
ATTORNEY

UNITED STATES PATENT OFFICE

2,642,554

AUTOMATIC STEERING SYSTEM

Alan M. MacCallum, Maywood, N. J., assignor to
Bendix Aviation Corporation, Teterboro, N. J.,
a corporation of Delaware

Application January 23, 1947, Serial No. 723,829

4 Claims. (Cl. 318—28)

1

The present invention relates to an electric automatic pilot adapted for use with dirigible craft and one which may be applied equally as well to the automatic steering of both air and water craft.

In an electric automatic pilot various methods are employed whereby the displacement signal for each axis of control is derived from a related electrical instrument and transmitted to operate an electric servomotor of the related control surface so that a rapid response on the part of all the necessary control surfaces is obtained. One of the methods in the creation and transmission of displacement signals utilizes the inherent characteristics of inductive devices in conjunction with an electronic direction discriminating device as more fully described in pending application Serial No. 516,488, filed December 31, 1943. While the electric automatic pilot described in the above-mentioned pending application performs in a manner superior to any other prior device, commercial operation has disclosed certain latent defects which are overcome by means of the novel arrangement of the present invention. For example, it is possible that upon the occurrence of certain conditions, the automatic pilot of the above copending application may be subjected to a hard-over signal of sufficient magnitude to throw the craft out of control. Moreover, as a result of the arrangement of signal devices and amplification channels there utilized, one sided control and/or false operation may be obtained.

An object of the present invention, therefore, is to provide a novel and improved automatic steering system for mobile craft.

Another object of the present invention is to provide novel safety features in an automatic pilot which will increase the safety factor in the flying of aircraft.

A further object is to provide novel improvements in automatic steering systems which will remove latent sources of danger heretofore existing therein.

A still further object is to provide a novel safety feature whereby the possibility of creating a hard over control signal has been eliminated from an automatic pilot.

Another object is to provide novel means whereby the occurrence of one sided control is eliminated from the operation of an automatic pilot.

A further object of the present invention is to provide novel means whereby the occurrence of false operations in the functioning of an automatic pilot is reduced to a minimum.

The foregoing and other objects and advan-

2

tages of the invention will appear more fully hereinafter from a consideration of the detailed description which follows, taken together with the accompanying drawings wherein one embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawings are for illustrative purposes only, and are not to be construed as defining the limits of the invention, reference being had for this purpose to the appended claims.

In the drawings, wherein like reference numerals refer to like parts:

Figure 1 is a schematic diagram and representation of the rudder channel of the automatic pilot.

Figure 2 is a schematic diagram and representation of the elevator and aileron channels of the automatic pilot.

Figure 3 is a schematic diagram of the electronic direction discrimination device and amplifier.

For a better understanding of the present invention, reference is made to the copending application referred to above wherein the theory and operation of the electric pilot hereof is fully set forth. As there shown, inductive transmitting devices, comprising three phase wound stators inductively associated with wound rotors connected to the craft's source of alternating current potential, are provided, and connected to reference means responsive to axial deviations of the craft from neutral axes for generating electrical displacement signals resulting from such deviations. In response to the deviations, potentials are generated in the stator windings of each transmitter proportional, respectively, to the angular position of each stator winding of each transmitter with respect to the related rotor windings and are transmitted to three phase wound stators of inductive receiver devices having wound rotors inductively associated therewith. For a no displacement condition of the craft about any of its axes, a condition of electrical equilibrium exists between the transmitters and receivers whereby the electrical axes of the receiver rotors are normal to the resultant magnetic fields of the receiver stators so that no potentials are induced within the various receiver rotor windings. As soon, however, as an angular displacement of the craft occurs about its various axes the transmitter rotors are angularly displaced relative to their related stators generating new values of potential in the latter whereby the condition of equilibrium previously existing between the transmitters and receivers is destroyed. In this manner the direction of the resultant magnetic fields of the re-

ceiver stators are changed so that they are no longer normal with the electrical axes of the receiver rotors whereby potentials are induced in the latter whose magnitudes are proportional to the amount of angular deviations from the various neutral axes.

Deviations of the craft from the neutral axes in one direction induces in the receiver rotors potentials whose magnitudes are proportional to the amount of deviation and having definite phases or polarities with respect to the craft's source of alternating current potential. Deviations of the craft from the neutral axes in the opposite direction induces in the receiver rotors potentials whose magnitudes are proportional to the amount of deviations but having phases or polarities 180° out of phase with those induced during deviations in the first direction.

The phase shift in the potentials of the receiver rotors occurring as the result of different directions of deviation of the craft from the neutral axes is independent of the amount of deviations, the amount affecting only the magnitudes of potentials induced in the receiver rotors. The direction of deviation determines whether the potentials of the receiver rotors are in phase or 180° out of phase with the craft's source of alternating current potential. Signal potentials are thus created whereby the direction of deviations determines the phase shift and the amounts of deviation determine the magnitude of the potentials.

The axial displacement signals created by a change of the craft's attitude are amplified in order to operate the servomotors of the related control surfaces. These signals are impressed upon the grid of an amplifier tube of either the rudder, aileron or elevator channels, the plate of which connects through a pair of parallel leads with the grids of two phase discriminating tubes, the anodes of the latter being connected to opposite terminals of a grounded split secondary winding of a potential transformer thus making the plate potentials of the discriminator tubes 180° out of phase with each other. Saturable transformers connect with the plate circuits of the discriminator tubes and with the related servomotors so that the latter are energized in response to displacement signals, the direction of operation depending upon the phase of the incoming displacement signals which, in turn, determine the conductivity of one or the other of the discriminator tubes.

One disadvantage encountered with the use of the above discussed interdependent signal sources has been that in the event of an open or short circuit in the connection of the three phase stators of the transmitting and receiving devices, sudden unbalanced potentials are induced in the receiver rotors creating hard-over signals which are applied to the related control surfaces causing the craft to be thrown out of control.

To the end that the foregoing disadvantage may be overcome, the novel arrangement constituting the subject matter of the present invention is provided with the use of which interdependent signal sources have been eliminated. For this purpose single phase variable inductive devices comprising single phase wound stators associated with single phase wound rotors have been provided. As shown in Figure 1 of the drawings, three such devices 10, 11 and 12 are utilized in the rudder channel. Device 10 comprises a single phase stator 13 and a single phase

rotor 14 which is connected to a shaft 15 which, under certain conditions described more fully in the aforementioned application, is displaced angularly in accordance with a displacement signal developed by a gyro stabilized earth inductor compass 16 to develop a corresponding signal in stator winding 13.

Device 11, on the other hand, comprises a single phase stator 17 and an inductively coupled single phase rotor 18 secured to a trunnion 19, of a rate of turn gyroscope 20 while device 12 comprises a single phase stator 21 and an inductively coupled single phase rotor 22 connected to a shaft 23 which is driven through a gear system 24 by a rudder servo 25. Angular displacement of any one or all of shafts 15, 19 and 23 displaces the magnetic fields of rotors 14, 18 and 22, which are connected through suitable resistors 26 with the craft's source of alternating current (not shown), from a normally electrically balanced condition relative to stators 13, 17 and 21 so that signal potentials are induced therein. The potentials of the various stators are impressed across the fixed terminals of resistors 27, 28 and 29, the latter two being variable for a purpose to presently appear and engaged by slidable contacts 30 and 31, and fed in series to the input of the rudder channel amplifiers 32 whose output is connected by way of leads 33 with motor 25.

Where the deviation of the craft from a neutral axis necessitates the corrective action of more than one element of control such as the rudder channel, for example, the signal voltage in order to be a function of all the elements of control, must of necessity be the algebraic sum of the signals of all the elements of control and for this reason all the sources of signal potential must be connected together in series and in phase with each other. This becomes apparent in view of the fact that were not the individual signal potentials in phase they could be added only vectorially whereby a signal potential would be derived which would not be a function of all the elements of control. This object is attained by connecting the resistors 26 in series with the windings of rotors 14, 18 and 22 to maintain the signal voltages in phase, and by arranging resistors 27, 28 and 29 across the stator windings to maintain the amplitudes of the signal voltages substantially equal for equal displacements of their related rotor windings, in which event the phases of the signal potentials of each element of control can be initially adjusted so that all will be maintained in phase with each other and their amplitudes for equal displacement of their related rotors maintained substantially equal.

As in the case of the rudder channel, the three phase wound inductive devices have been eliminated from the aileron and elevator control channels and in their stead, in accordance with the present invention, single phase variable inductive devices have been provided. As shown in Figure 2 of the drawings, an inductive bank device 34 is provided having a single phase stator 35 and a single phase rotor 36 connected to a trunnion 37 of a gyro vertical 38. For elevator control, a second single phase variable inductive device is provided having a single phase stator 39 and a single phase rotor 40 connected to a trunnion 41 of the gyro vertical.

Bank device 34 is connected in series with the input of the aileron channel of an amplifier 88 and with a single phase wound stator 43 of a

follow-up device 44 having associated therewith an angularly movable single phase rotor 45, the latter being displaceable through a reduction gear system 46 by a servomotor 47 which is connected to the output of the amplifier aileron channel by way of leads 48.

Stator 39 of the pitch device 42 is connected in series with the input of the elevator channel of amplifier 88 and with a single phase wound stator 49 of a follow-up device 50 having associated therewith an angularly movable single phase rotor 51 which is displaceable through a reduction gear system 52 by way of a servomotor 53, the latter being connected to the output of the amplifier elevator channel by way of leads 54. Stators 43 and 49 of the follow-up devices 44 and 50 have resistors 55 and 56 arranged across their terminals which are engaged by adjustable contacts 57 and 58 while rotors 45 and 51 connect with the craft's source of alternating current (not shown) through resistors 59 and 60.

In the foregoing manner, the use of interdependent signal devices in the rudder, aileron and elevator channels of an automatic pilot and their surrounding disadvantages have been eliminated. With the novel arrangement of single phase variable inductive devices connected in series no signal will be communicated to the grids of the amplifier channels in the event of a break in their connection as distinguished from the hard-over signals previously developed by a break in the connections of interdependent signal sources.

While the novel arrangement set forth above has eliminated the possibility of hard-over control signals, a break in the connecting lines to grids 61, 62 and 63 of amplifier tubes 64, 65 and 66 of the rudder, aileron and elevator channels, shown in Figure 3, will result in picking up stray potentials and communicating them to the grids which are provided with a normally negative bias. Such stray potentials are normally greater than the negative grid bias but smaller than the signal potential developed by the inductive devices whereby operation of the amplifier will occur in response to the stray potentials resulting in false operation of the related control surfaces. To the end that false operation due to stray potentials may be overcome, a negative cut-off bias is impressed upon the grids 61, 62 and 63 from the negative sides of batteries 67a, 68a and 69a through resistors 67, 68 and 69, such bias being of a magnitude greater than any stray potential that may be developed because the resistance value of each of the resistors 67, 68 and 69 is greater than the respective input impedances to the vacuum tubes 64, 65 and 66.

By the novel provision of the negative cut-off bias on the grids through resistors 67, 68 and 69 the amplifier channels are rendered inoperative and unresponsive to all voltages applied to grids 61, 62 and 63 having a magnitude less than the applied negative bias but will operate in response to signal voltages. The normal low impedance input circuits act as short circuits on the cut-off bias supplied through resistors 67, 68 and 69. In this manner novel provision is made in the input circuits of the amplifier channels so that in the event open circuits occur, a negative cut-off bias is automatically applied to the input tubes causing the channels affected to go dead rather than subjecting the related control surfaces to the effect of stray pick-up voltages.

A further disadvantage resulting with the use

of the automatic pilot of the above referred to copending application resided in the possibility of one sided control in any one or more of the control channels of the amplifier due to the fact that the heater circuits of the discriminator tubes of each channel were connected in parallel. Thus, the burning out of one heater element of one discriminator tube of one channel resulted in blocked operation for one side of that control channel whereby response was available for only one direction of deviation from a neutral axis. To the end that the occurrence of one-sided control in any one or more control channels may be eliminated, heater elements 70, 71 of discriminator tubes 72, 73 of the amplifier rudder channel as well as heater elements 74, 75 of tubes 76, 77 of the amplifier aileron channel and heater elements 78, 79 of tubes 80, 81 of the amplifier elevator channel are connected in series with suitable current sources such as batteries 82, 83 and 84, for example, by way of leads 85, 86 and 87 as shown in Figure 3. With this novel arrangement, if any one of the heater elements of any one or more control channels burns out, the whole channel automatically becomes inoperative thereby preventing one sided control in any one or more of the control channels.

Although but one embodiment of the invention has been illustrated and described, various changes and modifications in the form and relative arrangement of parts, which will now appear to those skilled in the art, may be made without departing from the scope of the invention. Reference is therefore to be had to the appended claims for a definition of the limits of the invention.

I claim:

1. In an automatic pilot for aircraft having a movable control surface thereon and a servomotor for operating said surface, reference means including a variable inductive device having a single phase wound stator and an inductively coupled angularly movable single phase wound rotor for developing in said stator a signal in response to a departure by said craft from a predetermined position for operating said motor, rate of departure means comprising a rate-of-turn gyroscope and a second variable inductive device controlled thereby and having a single phase wound stator and an inductively coupled angularly movable single phase wound rotor for developing in said second-named stator a signal in response to the rate of departure by said craft from said predetermined position for modifying the operation of said motor, a third variable inductive device comprising a single phase wound stator and an inductively coupled angularly movable single phase wound rotor responsive to the operation of said motor for developing in said last-named stator a follow-up signal for further modifying the operation of said motor, means connecting said rotors for energization from a source of alternating current, means connecting said stators in series with one another for controlling operation of said motor, means connected to the rotors of at least two of said variable inductive devices for controlling the phase of the signal developed therein within an angle of less than 180 degrees, and means connected to the stator of at least two of said variable inductive devices for controlling the magnitude of the signal developed therein independently of the phase of the signal.

2. In a device of the kind described wherein a signal is developed in response to a change in

7

condition, thermionic means having an input of relatively low impedance adapted to receive the signal, a relatively high impedance connected to said input, and biasing means cooperating with said relatively high impedance and providing for the passage of signals to said thermionic means during normal operation and biasing said thermionic means to cutoff, in the event of an open circuit in said input, and rendering said thermionic means inoperative to stray signals.

3. The combination with an automatic pilot for an aircraft having a movable control surface thereon and a servomotor for operating said surface together with reference means for developing a signal in response to a departure by said craft from a predetermined position for operating said motor, of thermionic means interconnecting said motor with said reference means and having an input of relatively low impedance adapted to receive the signal, a relatively high impedance connected to said input, and biasing means connected to said relatively high impedance to bias said thermionic means to cutoff in the event of an open circuit in said input.

4. The combination with an automatic pilot for an aircraft having a movable control surface thereon and a servomotor for operating said surface, together with reference means including a

8

variable inductive device having a single phase stator winding and an inductively coupled angularly movable single phase rotor winding for developing in one of said windings a signal, in response to a departure by said craft from a predetermined position, for controlling said motor, of thermionic means having an input of relatively low impedance and an output, means connecting said motor to said output, means connecting the signal developing winding to said input, a relatively high impedance connected to said input, and biasing means connected to said impedance to bias said thermionic means to cutoff in the event of an open circuit in said input.

ALAN M. MACCALLUM.

References Cited in the file of this patent UNITED STATES PATENTS

Number	Name	Date
1,942,587	Whitman	Jan. 9, 1934
2,014,825	Watson	Sept. 17, 1935
2,115,086	Riggs	Apr. 26, 1938
2,209,369	Wills	July 30, 1940
2,336,492	MacKay	Dec. 14, 1943
2,416,097	Hansen et al.	Feb. 18, 1947
2,429,642	Newton	Oct. 28, 1947
2,464,629	Young	Mar. 15, 1949