ELECTRONIC CONTROL DEVICE FOR FUEL SUPPLY TO COMBUSTION ENGINE

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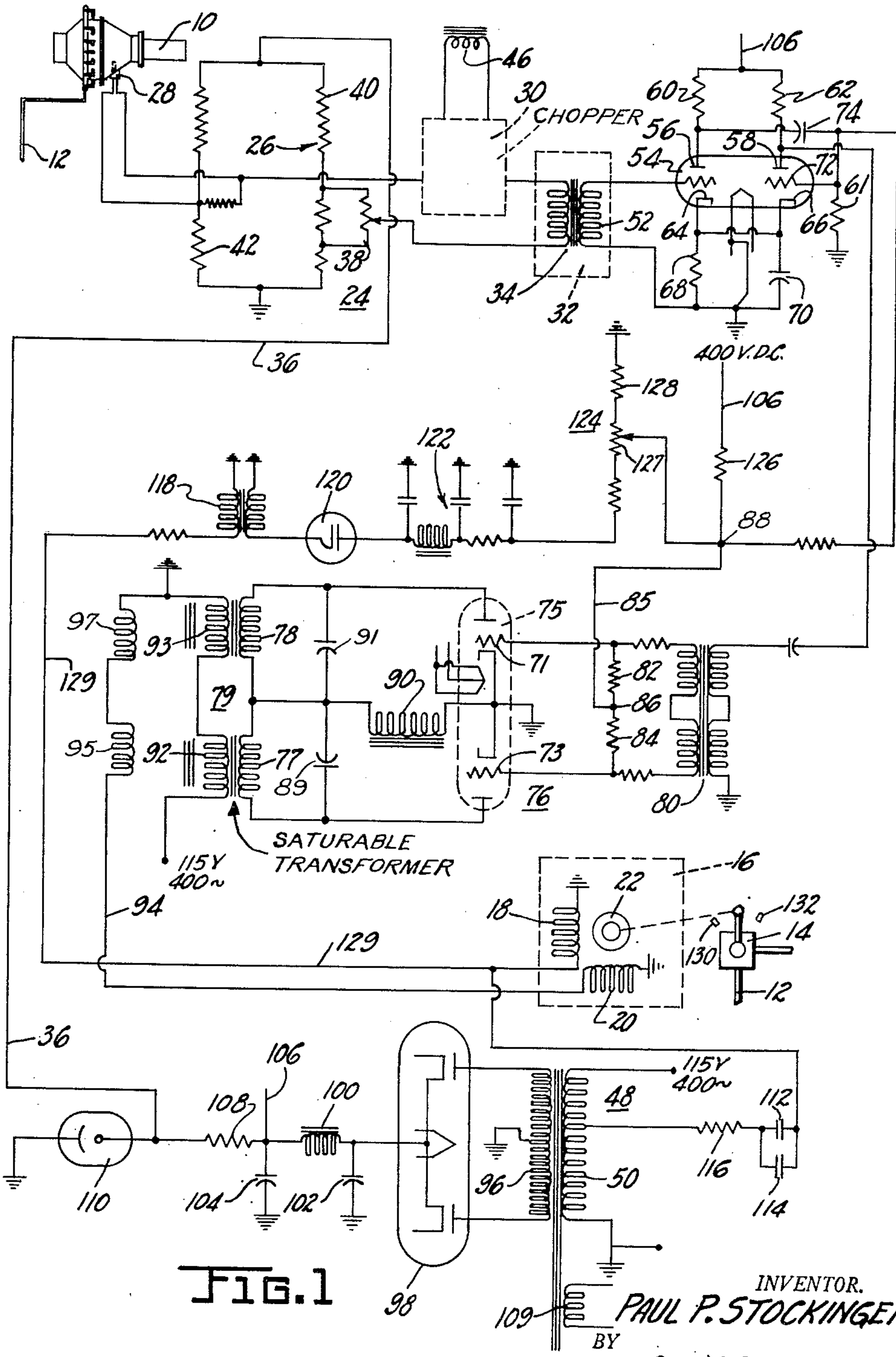

FIG. 1

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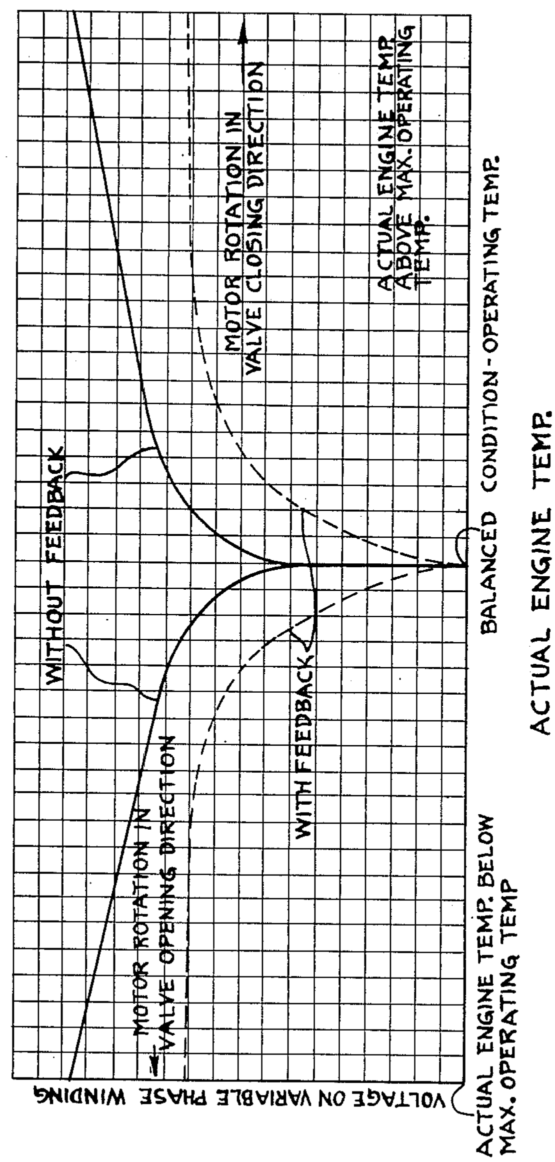

FIG. 2

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ELECTRONIC CONTROL DEVICE FOR FUEL SUPPLY TO COMBUSTION ENGINE

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This invention relates to electronic control apparatus. The invention is concerned more particularly with electronic fuel control means for aircraft engines, such for example as turbo-prop, jet, and gas turbine engines.

It is an object of the invention to provide electronic control apparatus for regulating the flow of fuel to a jet engine in accordance with burner inlet temperature.

An important object of the invention resides in the provision of electronic control means wherein a feedback circuit connects an electrical machine to an amplifier input for modifying the input signal.

A still further object of the invention resides in the provision of electronic means for modifying the control of an electrical machine by feeding back a signal corresponding to the load on said machine.

Another important object of the invention is to provide a feedback circuit which connects a winding of an electrical machine to a control circuit for modifying the electrical signal to the machine.

The above and other objects and features of the invention will be apparent from the following description of the apparatus taken in connection with the drawings which form a part of this specification and in which:

Figure 1 is a schematic wiring diagram of the device of the invention; and

Figure 2 is a graphical representation of the performance of the device with and without feedback.

Referring now to the drawing the reference numeral 10 designates a jet engine having a fuel supply system comprising a pipe line 12, which connects a fuel supply source, not shown, to a combustion chamber of the engine, not shown. The fuel passing through this pipe line 12 is controlled by a valve 14, located in the line between the source and the combustion chamber.

The valve 14 is mechanically connected to an electrically actuated mechanism or machine 16, which in the present illustration, is in the form of a two phase motor, having an exciting winding 18, control winding 20, and a rotor 22.

For controlling fuel flow to the engine via the valve 14, the electrical machine 16 is connected in an electrical network comprising an electrical device 24 which produces signals representative of temperature variations from a predetermined datum. The device includes a bridge 26, thermocouple 28, chopper 30, and transformer 32. The thermocouple 28, which is located at a predetermined point in the engine combustion chamber, is connected in series relationship to the chopper or interrupter 30, and primary winding 34 of transformer 32. Line 36 provides a source of regulated direct voltage to the bridge 26. This regulated voltage is connected in series differential with the thermocouple voltage via the bridge. The resistances of the bridge are of such values that when the thermocouple voltage output is a predetermined value, such as zero, for example, the output voltage or signal due to the input regulated voltage represents a predetermined datum temperature to which the engine temperature is referred as a basis for controlling fuel flow

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to the engine. It will be noted that the regulated voltage is connected to the bridge so that it appears across a temperature setting potentiometer 38, dropping resistors 40, and a nickel cold junction compensating resistor 42. The resistance of the resistor 42 varies linearly with its temperature and the resulting change in IR drop across the resistor just compensates for the change in thermocouple voltage due to variations in cold junction temperature so that the resultant voltage reflects actual engine temperature. The predetermined datum temperature is usually the maximum safe temperature at which the engine will operate. The regulated voltage from the bridge output reflects this datum temperature and is equivalent to and balances out the aforesaid resultant voltage when the actual engine temperature equals the reference temperature. In arriving at this balance, the said resultant voltage produced at the desired maximum engine temperature is balanced out by manipulating the bridge 26 to produce an equivalent voltage. The voltage required to balance out said resultant voltage represents the predetermined datum temperature.

The purpose of the chopper is to change the continuous direct current, which flows due to the resultant differential direct voltages, into a pulsating direct current, for passing the same through primary 34 of the transformer 32. The chopper is connected to secondary winding 46, of a power transformer 48, having a primary winding 50. The current, which flows in the primary 34, will induce a voltage in secondary winding 52 proportional to the amount of current flowing due to the differential voltage. The phase of this induced voltage, in secondary winding 52, will depend upon the direction of unbalance between the thermocouple voltage and the output regulated direct voltage from the bridge 26.

The secondary voltage established in winding 52 is impressed on the grid-cathode circuit of a twin triode tube designated by numeral 54, which provides two stages of amplification. Plates 56 and 58 of the tube 54 are connected to a 400 volt direct voltage source through resistors 60 and 62. The associated cathodes 64 and 66 of the anodes 56 and 58 respectively, are connected to the return side of the direct voltage source via a cathode bias resistor 68 and a cathode by-pass capacitor 70. The output of the plate-cathode 56 and 64 is coupled to grid 72 by the resistor 61 and capacitor 74. The output of the aforesaid two stages of amplification is applied to the grids 71 and 73 of tube 75 arranged in a discriminator network 76, the output of which is in turn connected to windings 77 and 78 of a saturable transformer 79. This type of transformer is also referred to as a saturable reactor or as a magnetic amplifier. A transformer 80 is interposed between the output of the second stage of amplification and the discriminator. The grid-cathode circuits of the discriminator include a voltage divider having resistors 82 and 84, connected by a wire 85, which extends from midpoint 86 to a point 88 which forms a junction for the regulated direct voltage and a feedback circuit to be hereinafter discussed. A secondary winding 90, of the transformer 48, provides a suitable source of plate voltage when arranged in circuit, as shown, with by-pass condensers 89 and 91. Windings 92 and 93 of the saturable transformer are connected across a suitable electrical power source for energizing the windings. A wire 94 connects the output of windings 95 and 97 of the saturable transformer to the winding 20 of the two phase motor. The windings 95 and 97 are inductively related to windings 92 and 93 and are connected in bucking relationship. The output voltage of the saturable transformer is proportional to the current differential in the primaries 77 and 78. The phase of this voltage will vary depending upon which of the primaries is carrying current.

The power source for the network is supplied by the transformer **48**, whose primary is connected to any suitable line voltage and frequency, such as a 400 cycle 115 volt supply, not shown. In order to obtain the direct current required for operation of certain electrical devices in the network the transformer **48** is equipped with a secondary winding **96**, which is connected to a full wave rectifier **98**, the output of which is filtered by a choke **100**, condensers **102** and **104**, and then impressed on line **106**. A resistor **108** reduces the line voltage of **106** to a suitable value for application to the line **36** which supplies the bridge **26**. A voltage regulator **110** maintains the bridge reference voltage substantially constant. A secondary winding **109** furnishes current to the various tube filaments.

The exciting winding **18**, which represents the fixed phase of the motor **16**, is connected to the primary of the transformer as shown, through condensers **112** and **114**, arranged in parallel, and a series resistor **116** thus providing a resonant circuit. The resistor **116** creates a condition of frequency insensitivity within a prescribed range in the resonant circuit. The resonant circuit constants are so chosen that resonance is improved as the motor speed increases. However, because of the circuit parameters used, resonance can not be obtained at the top speed of the motor. This insures against passing through resonance, which, of course, is undesirable for the instant use. The feedback voltage will not be adversely affected by changes in frequency which cause a voltage change in the resonant circuit of less magnitude than a voltage change due to a change in inductive reactance in that circuit. This circuit further provides an out-of-phase relationship between the voltages impressed on the windings **18** and **20**.

A degenerative circuit including a transformer **118**, rectifying tube **120**, filtering network **122**, and resistance network **124**, supplies a feedback voltage to the grids **72**, and **71—73**, of the tubes **54** and **75** respectively. A wire **129** connects the feedback circuit to the resonant circuit as shown. The feedback voltage is fed into the resistance network **124**, which in turn is connected to the direct voltage source line **106**, so that a portion of the feedback voltage is cancelled out, with the remainder being impressed on the grids **71**, **72**, and **73**. This feedback voltage, which is taken from the resonant circuit and applied to these grids in the form of a negative bias, varies in proportion to the motor speed. Hence the grid bias feedback voltage will have a fixed magnitude for a given motor speed. As the motor speed increases the negative bias on the grids **71**, **72**, and **73** increases, thus reducing the gain of the amplifier. This action provides more sensitive valve control at the balance point and minimizes oscillations. See Figure 2. From a comparison of the two curves it is obvious that a more stable system is assured with the feedback than without it. The direct voltage source of line **106** is obtained from the power supply filter network, and fed into the resistance network **124** comprising resistors **126**, **127**, and **128**.

The motor **16** operates the valve **14** between stops **130** and **132** and is stalled when against either stop. Any time the signal representing the actual engine temperature balances out the signal representing the predetermined datum temperature the motor will stop, if only for an instant, and start up again as soon as a temperature difference exists between actual engine temperature and the reference temperature.

Operation of the control device is as follows:

If an engine operating condition is assumed wherein the differential between the thermocouple resultant voltage and the regulated output direct reference voltage, from the bridge **26** is zero, no current flows in the primary winding **34**, and hence the current through the control winding **20** of the two phase motor is zero. At this time a state of balance is reached as shown in Figure 2, and the actual engine temperature is equal to the reference temperature.

At the time this state is reached the valve may be open or closed, or in a position intermediate the open and closed position. For sake of illustration it will be assumed that a balance was reached when the valve was in an intermediate position. Any deviation in actual engine temperature (the temperature change may be up or down) will upset the balance condition causing current to flow in the winding **20**. If, for example, the unbalance is due to the actual engine temperature being greater than the reference temperature the signal will send a current through the winding **20** in a direction tending to cause the motor to move the valve **14** in a closed direction. Initial motor rotation increases the negative voltage feedback bias on the grids, hence reducing the gain of the amplifier; but as the balance point is approached the gain of the amplifier is gradually increased. This action of the feedback circuit prevents overshooting of the motor by reducing the applied voltage to winding **20** in accordance with motor speed above a predetermined value;

A temperature deviation in the other direction, that is, where the actual engine temperature is less than the reference temperature the signal will send a current through the winding **20** in a direction tending to cause the motor to move the valve **14** to an open position.

Although this invention has been described in connection with certain specific embodiments, the principles are susceptible of numerous other applications that will readily occur to persons skilled in the art.

Having thus described the various features of the invention, what I claim as new and desire to secure by Letters Patent is:

1. A mechanism for controlling the fuel supply to an engine comprising a fuel valve, a two phase motor drivably connected to the valve and being provided with a first winding adapted to have a fixed phase voltage applied thereto and a second winding adapted to have a variable phase voltage applied thereto, means producing a variable phase voltage across said second winding including a thermocouple, the cold junction of which is compensated against variations in ambient temperature, and a regulated direct current reference voltage sources having their outputs connected in series differential, an amplifier having a saturable transformer output stage, and a feedback circuit connecting said first winding to the amplifier.

2. A mechanism for controlling the fuel supply to an engine comprising an electric motor for actuating a fuel valve, said motor being provided with two windings one of which is adapted to have a fixed phase voltage applied thereto and the other of which is adapted to have a variable phase voltage applied thereto, means for producing a variable phase voltage across said other winding including a thermocouple mounted in the engine for sensing actual engine temperatures with means for compensating against variations in cold junction values, a source of regulated direct current reference voltage for setting up an output voltage corresponding to a preselected temperature with which it is desired to compare the actual engine temperature, said thermocouple output voltage being connected in series differential with said bridge output voltage, an amplifier, including a control grid, a pair of stops, one of which stalls said motor when the valve is in closed position and the other of which stalls said motor when the valve is in open position, and a feedback circuit connecting said one winding to the control grid of said amplifier so that the grid is biased more positive when the motor is stalled and less positive when rotating.

3. A mechanism for controlling the fuel supply to an engine comprising an electric motor for actuating a fuel valve, said motor being provided with an exciting winding and a control winding, said exciting winding being adapted to have a fixed phase voltage applied thereto,

and said control winding being adapted to have a variable phase voltage applied thereto, means for producing a variable phase voltage across said control winding including a thermocouple mounted in the engine for sensing actual engine temperatures, a regulated source of direct current voltage representing a predetermined temperature datum, a resistance network, containing a temperature compensating resistor, in which said regulated direct current voltage is compared with the thermocouple voltage, means for converting the steady direct current resultant signal from the resistance network into a pulsating direct current, an amplifier containing a control grid, transformer means for connecting the output of said amplifier to said electric motor, and a feedback circuit connecting said exciting winding to said control grid.

4. In combination, an electrical machine equipped with current carrying windings, with one of said windings adapted to be connected to a fixed phase voltage, means for establishing and applying a variable phase voltage to another of said windings consisting of a regulated direct current signal representing a predetermined reference temperature and a second voltage consisting of a thermocouple signal including means for compensating said signal against variations in cold junction values representing an actual temperature condition, means for comparing said reference signal and said thermocouple signal, electronic means for amplifying the resultant of said signals, magnetic amplifier means for further amplifying said resultant signal and for coupling said signal to said control winding, and a feedback circuit connecting said one winding to said electronic means.

5. In combination, an electrical machine equipped with current carrying windings, a resonant supply circuit including one of said windings, means for establishing and applying a voltage to another of said windings comprising a device for creating a regulated direct current voltage which represents a predetermined reference temperature and a voltage which represents a sensed temperature value, means for creating a resultant voltage by comparing said reference temperature voltage with said sensed temperature voltage, amplification means including a saturable transformer for amplifying said resultant voltage, and a feedback circuit connecting said resonant circuit to said means for altering said first mentioned voltage.

6. In combination, a fuel valve, a two phase motor drivably connected to said valve having one winding to which a fixed voltage is applied and a second winding to which a variable voltage is applied, a resonant supply circuit including said one winding, means for producing a voltage which reflects a condition to be observed, an amplifier including a saturable transformer interposed between said last named means and said second winding, and a feedback circuit including, in series, a transformer, a rectifier, a filter, and a resistance network connecting said resonant circuit to said amplifier.

7. In apparatus for controlling the fuel supply to an engine, the combination of a fuel valve having a movable

control member, motor means drivably connected to the fuel valve for moving said control member, circuit means for controlling the motor means and including a bridge circuit connected to a regulated voltage source to provide a first voltage representing a predetermined temperature datum, a thermocouple for providing a second voltage representing actual engine temperature and connected in series differential with said first voltage, an amplifier having its input connected to receive a control voltage from said series differential connection, said amplifier having an output, saturable reactor means connected between the output of said amplifier and said motor means, and an inverse feedback circuit connected between the motor means and the input of said amplifier for providing a damping signal to said amplifier as a function of the speed of movement of said control member.

8. In apparatus for controlling the fuel supply to an engine, the combination of a fuel valve having a movable valve control member, a motor device drivably connected to said fuel valve for moving said valve control member, said motor device including a field winding, first circuit means having a first output connected to provide a variable phase voltage across said field winding, said first circuit means including a thermocouple, second circuit means having a second output and including a source of regulated direct current reference voltage, with said first output and said second output being connected in series differential, an amplifier having an input connected to said series differential connection and responsive to the resultant of said variable phase voltage and reference voltage, said amplifier having an output, a saturable reactor connected between the output of said amplifier and said winding, and a feedback circuit inductively related to said winding and connected to the input of said amplifier for varying the gain of said amplifier as a function of the speed of movement of said valve control member.

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