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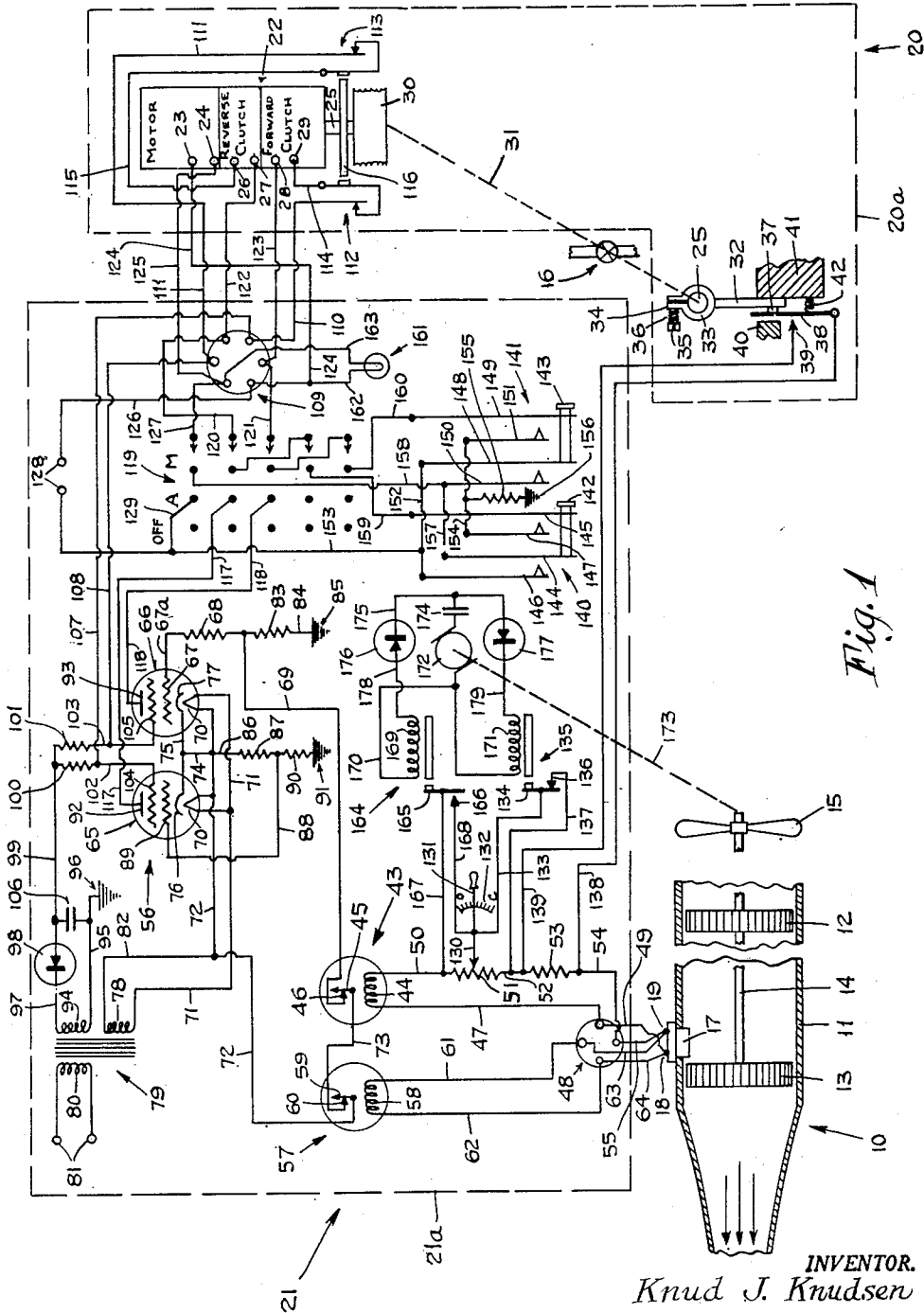
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JET ENGINE FUEL CONTROL

Filed July 5, 1947

2 Sheets-Sheet 1



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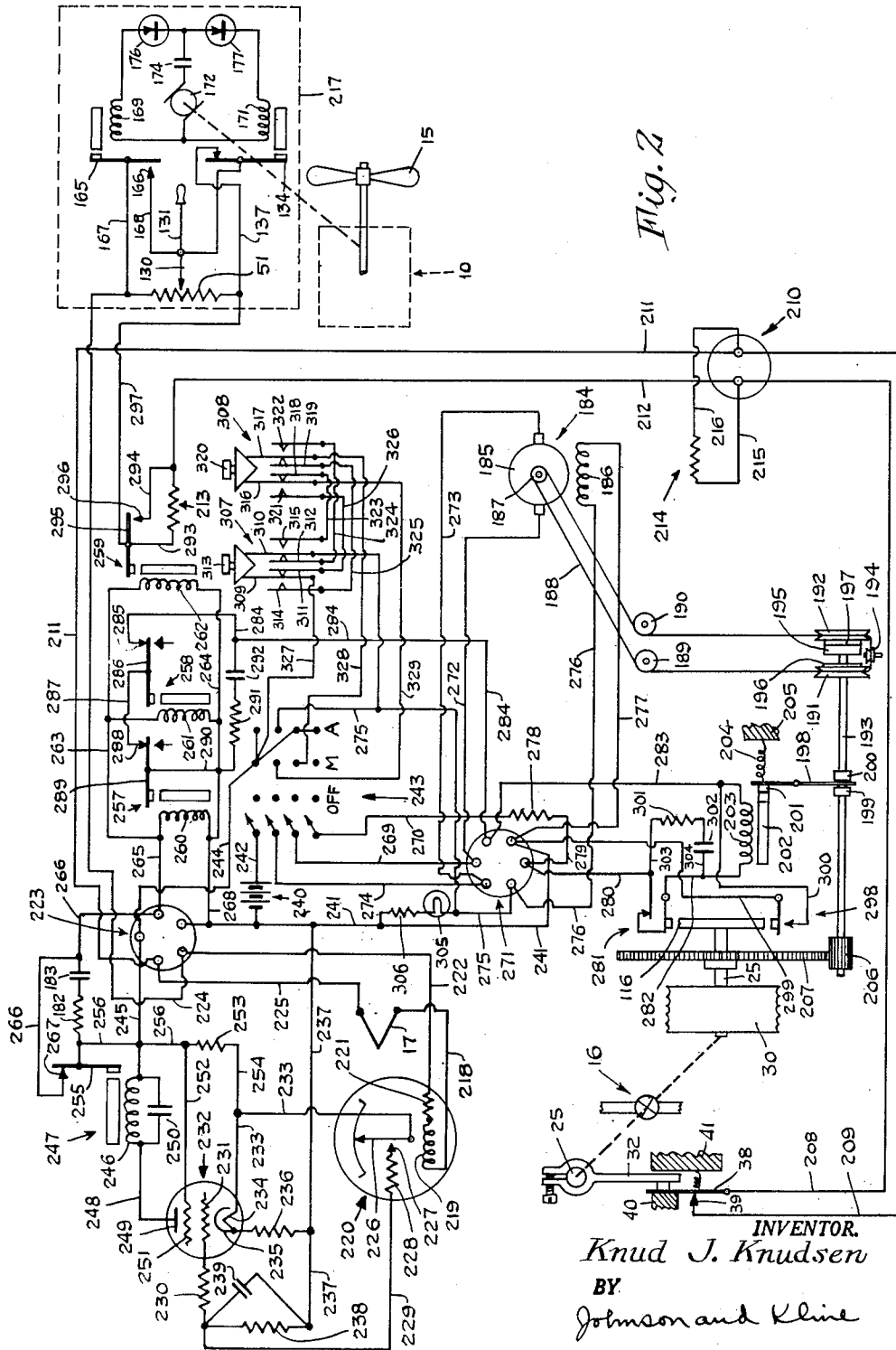
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UNITED STATES PATENT OFFICE

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JET ENGINE FUEL CONTROL

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This invention relates to the throttling or control of fuel in jet-turbine aircraft engines, for controlling engine speed or power, and temperature.

An object of the invention is to provide an improved method of control and an improved manually-settable, automatic regulating fuel control device for a jet-turbine engine whereby an extremely quick-acting regulation is had in response to changes in the setting of the device, with the result that dangerous overheating and racing of the engine is prevented.

Another object of the invention is to provide an improved regulating jet-engine fuel control method and device whereby for any throttle setting the engine temperature and speed or power will be accurately and reliably maintained within a relatively narrow range.

A further object of the invention is to provide improved indicating means in conjunction with a regulating, settable fuel control for a jet-turbine engine as characterized above.

Still another object of the invention is to provide, in a jet-engine control device as above, improved and quick-acting automatically operative means for opening or closing the throttle in response to conditions caused by sudden climbing or diving of the aircraft, thereby to quickly limit the engine temperature and speed to a safe value during such maneuvers.

Yet another object of the invention is to provide a regulating jet-engine control as above, having reliable safety means for closing the throttle when the engine temperature becomes dangerously high, thereby to prevent damage and inoperativeness of the engine.

Another object of the invention is to provide a control device having characteristics as above, which is of relatively simple and economical construction and is reliable in operation over an extended period of use.

A further object of the invention is to provide a regulating control according to the foregoing and wherein a changeover may be quickly and easily effected from automatic to manual control and vice versa.

In accomplishing these objects there is provided, according to the invention, a novel method and apparatus whereby a deflectable member is made to continually and rapidly move back and forth or oscillate with an amplitude and period which is proportionate with the temperature of the engine, this being effected in part by a heat-responsive means. This oscillating movement, through a novel relay device which in one em-

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bodiment of the invention comprises a bank of blocking, relay vacuum tubes, is made to actuate a reversibly movable powered means in such a manner that the said means moves in one direction when the amplitude and period of oscillation of the member are greater than a predetermined value, and moves in the other direction when the amplitude and period are less than said value.

The powered means is connected to drive the fuel valve of the engine, thus to effect an automatic control.

The deflectable member of the control is made to rapidly oscillate by an organization which I term an "anticipator" and which includes a component actuated concurrently with movement of the powered means and fuel valve, said component being connected to influence a driving means for the deflectable member, which driving means is connected to the heat-responsive means under the control of the temperature of the engine. The term "anticipator" is applied to this organization since it anticipates the effect, on the heat-responsive means, of a change in engine temperature, as will be later brought out in detail.

The above assemblage, except for the fuel valve, constitutes in general an oscillatory actuator device, since it is arranged to be, independently of the engine temperature, in a state of continual oscillation or hunting, and by virtue of this an extremely rapid regulation is had in response to engine temperature changes, or to intended changes in the setting of the control, this being accomplished in spite of a relatively great time lag being present in the transmission of heat from the engine to the heat-responsive means of the control. By this organization I effectively prevent overheating and racing of the engine, which may be of great danger in jet-turbine engines, resulting in inoperativeness and destruction.

In the specific embodiments of the invention illustrated herein the deflectable member and driving means therefor are parts of a sensitive instrument movement, and include the movable coil and field of said movement, which coil is connected with the heat-responsive means to be controlled thereby. The said movable coil controls contacts within the instrument movement which trigger the relay vacuum tubes, the latter in turn actuating the powered means which operates the fuel valve of the engine. Throttling is accomplished by a settable throttle member which varies a resistor included in the circuit

from the heat-responsive means to the instrument coil, said variation changing the relationship of the amplitude and period of oscillation of the deflectable member or coil of the instrument movement with respect to the temperature of the engine. Due to the sensitivity and accuracy of the components of the instrument movement, together with the oscillating or continually hunting characteristics of the control, the temperature of the jet-engine is held to narrow limits for a given throttle setting, and by the provision of suitably marked graduations at the throttle, the temperature of the engine may be indicated within close limits.

By cutting in or out, in its entirety, the throttling resistor, the temperature and consequently speed of the engine may be readily fully increased or decreased, and this resistor is therefore utilized in conjunction with relays and a propeller-acceleration responsive device to automatically quickly control or regulate the engine if the aircraft should unexpectedly climb steeply or dive, thereby to safeguard against excessive engine temperatures.

A second sensitive-instrument movement is provided, parallel connected with the first movement as regards the heat-responsive means, and having movable-coil controlled contacts so arranged and connected that, should the engine temperature become too great, the control will be taken away from the settable throttle of the device and the fuel valve will be automatically closed to reduce the fuel flow and consequently the temperature. Upon temperature reduction occurring, the settable throttle is automatically restored to control, and this organization therefore provides further for safety in the operation of the engine. The second instrument movement also provides a safety factor in that it will assume control to reduce the fuel supply if the first sensitive instrument movement should fail in its functioning.

The relay vacuum tubes and powered means controlled thereby are so arranged, as regards their energization, that changeover from automatic to manual control and vice versa is easily and quickly accomplished by use of a relatively simple circuit and switching means. To prevent delay in the changeover, the energization of the vacuum tubes is continued during manual operation, thereby enabling the control to be immediately effective when switched to automatic operation, without requiring a waiting period.

The entire control device, comprising the contact-controlling instrument movements, the vacuum tube relay means, reversible powered means for the fuel valve, and the anticipator mechanism, is of simple construction and involves relatively few parts considering its purpose and function, and is therefore relatively economical to manufacture.

Other features and advantages will hereinafter appear.

In the accompanying drawings:

Figure 1 is a schematic diagram showing one form of the control device made according to the invention, the device being illustrated in connection with a jet-turbine engine and fuel valve controlling the latter, and

Figure 2 is a schematic diagram showing another form of the control device made according to the invention, applied to a jet-turbine engine and fuel valve control therefor.

Referring to Fig. 1, a jet-turbine aircraft engine 10 is shown, the said engine being powered

by a heating medium such as a liquid fuel, and the engine having a casing 11 and turbine rotors 12 and 13 carried by a shaft 14, on which latter the aircraft propeller 15 is mounted.

The propeller 15 may be of the fixed pitch type, in which event increasing the fuel supply to the engine 10 will result in an increase in the speed of the shaft 14; or the propeller may be of the variable pitch type, in which case increasing the fuel supply and simultaneously changing pitch may result in a power increase with substantially constant shaft speed.

The temperature and speed or power of the engine 10, constituting variables, are controlled by a reversible control device 16 comprising a flow-control means in the form of a fuel valve which governs the flow of fuel to the casing 11, and within the latter a heat-responsive translating device 17 is mounted, the said device being preferably a thermocouple having terminals 18 and 19. The thermocouple 17 may be located in any desirable place in the casing 11, being shown, however, as located ahead of the turbine rotor 13. The response of the thermocouple 17 to a change in the temperature of the engine 10 may involve generally a time lag of approximately fifteen seconds.

The present invention provides an improved settable control in conjunction with the thermocouple 17 for automatically maintaining the temperature and speed or power of the jet-turbine engine 10 within any selected one of a plurality of different predetermined ranges, as for example, ranges within a low limit of 900° F. corresponding to idling speed of the engine, and a high limit of 2200° F. corresponding to a running speed at full power, of the engine, without danger of overheating of the engine due to a change of setting, or due to other circumstances.

This control is indicated as comprising two separate units, a fuel-valve actuator unit 20 blocked off by a broken outline 20a, and a control unit 21 blocked off by a broken outline 21a; however it should be understood that the various components of the control and circuits therefor may be segregated differently from the arrangement shown.

The units 20 and 21 together constitute an oscillatory actuator device in that they include a powered means for actuating the fuel valve 16, and in that the device is in a continual state of oscillation or hunting which is sustained independently of connection to the thermocouple 17. The arrangement is such, however, that the thermocouple 17 may control the period of oscillation and amplitude of the oscillating parts, within limits, thereby to ultimately control the setting of the fuel valve 16, and the method of control and organization of parts is such that the cited time lag of fifteen seconds between the thermocouple 16 and temperature of the engine 10 is anticipated, so to speak, in a manner to prevent wide swings of temperature of the engine beyond the settings of the control, and to provide an overall response time or time of regulation on the order of two seconds, the said time interval occurring between a change in the setting of the control and the establishment of the new temperature range in the engine 10.

The fuel-valve actuator unit 20 comprises a reversible powered means 22 which may be a Lear model 125-A or model 119-D actuator, such actuator consisting of an electric motor energized through terminals 23 and 24 and driving a shaft 25 the rotation and direction of turning of which

is controlled by electrically operated clutches energized through terminals 26, 27 and 28, 29 respectively. The shaft 25 of the powered means 22 carries a capstan 30 which is mechanically connected to drive the fuel valve 16 in one direction or the other, as indicated by the broken line 31.

The actuator unit 20 also includes part of the anticipator mechanism of the control, comprising an arm 32 mounted on the shaft 25 by means of a split collar 33, said collar having a pair of ears 34 continually urged together by a screw 35 and compression spring 36 carried by the screw. The arm 32 is thus frictionally mounted on the shaft 25 and may remain stationary while the shaft rotates in either direction.

Movement of the arm 32 between limits is made to control an electrical circuit, and for this purpose the arm has a projection 37 engageable with a pivotal contact arm 38 which is in turn cooperable with a stationary contact 39. Stops 40 and 41 are respectively engageable with the arms 39 and 32 to limit movement of these, and an extension spring 42 connects the arm 38 with the stop 41. By this organization clockwise rotation of the shaft 25 causes engagement between the contact arm 38 and contact 39, and counterclockwise rotation of the shaft 25 causes disengagement between the contact arm 38 and contact 39. As will be later described, the arm 38 and contact 39 are connected with the control unit 20 for the purpose of setting up a continuous rapid oscillation of the control device.

The control unit 21 comprises an electro-receptive instrument 43 in the form of a sensitive-instrument relay which may be of the type disclosed in my copending patent application S. N. 612,272, filed August 23, 1945, now Patent No. 2,508,862, and entitled "Electrical Relay." The instrument or relay 43 includes a permanent-magnet D. C. instrument movement, and has a movable coil 44 carrying a contact arm 45 which latter is cooperable with a stationary contact 46. The arm 45 constitutes a deflectable member which is movable between advanced and retracted positions. The coil 44 of the movement, when energized is deflected together with the arm 45, and said coil is connected by a wire 47 through a connector fitting 48 and wire 49 to the terminal 18 of the thermocouple 17. The coil 44 is also connected by a wire 50 to one end of a resistor 51 hereinafter also termed a throttle resistor, the other end of said resistor being connected by a wire 52 to one end of a second resistor 53, which I also term an anticipator resistor.

The remaining end of the anticipator resistor 53 is connected by a wire 54 through the connector fitting 48 and a wire 55 to the other terminal 19 of the thermocouple 17. The instrument coil 44 is thus energized through the resistors 51 and 53 from the thermocouple 17.

The contact arm 45 and stationary contact 46 are connected to a novel relay means 56, including a pair of vacuum tubes so arranged that operation of one tube blocks operation of the other tube and vice versa, all for the purpose of energizing one or the other of the clutches of the powered means 22 respectively according to whether the contacts 45, 46 are engaging or not engaging each other. A safety device is also incorporated in the control circuit for the said relay means and is operative to cause actuation of the powered means 22 and closing of the fuel

valve 16 if the temperature of the engine 10 should exceed a predetermined extreme value.

The safety device comprises a second electro-receptive instrument in the form of a sensitive-instrument relay 57 which may be similar to the relay 43, having a movable coil 58 and a contact arm 59 driven by the coil and engageable with a cooperable stationary contact 60. The movable coil 58 of the relay 57 is connected by wires 61 and 62 through the connector fitting 48 respectively to wires 63 and 64, which are in turn connected respectively to the terminals 19 and 18 of the thermocouple 17. Thus, the coil 58 is energized from the thermocouple 17 simultaneously with energization of the coil 44.

The blocking relay means 56 controlled by the contacts 45, 46 of the instrument relay 43 includes vacuum tubes 65 and 66, which may be type 6AK5, the control grid 67 of the tube 66 being connected by a wire 67a to one end of a grid resistor 68 (which may be of two megohms resistance), the other end of which resistor is connected by a wire 69 with the stationary contact 46 of the instrument relay 43. Both heaters 70 of the vacuum tubes 65 and 66 are connected in parallel by wires 71 and 72, the latter wire being connected with the contact arm 59 of the safety relay 57, and the stationary contact 60 of the safety relay being connected by a wire 73 with the contact arm 45 of the instrument relay 43. The contact means of both of the instrument relays 43 and 57 are thus connected in series so as to control the polarization of the control grid 67 of the vacuum tube 66, and in connection with such polarization, a wire 74 connects the wire 72 of the vacuum tube heaters with a jumper wire 75 connected between the cathodes 76 and 77 of the tubes 65 and 66 respectively.

The heaters 70 of the vacuum tubes are energized from a filament winding 78 (which may be 6 volts) of a power transformer 79 having a primary winding 80 connected with supply terminals 81, the said filament winding having one end connected by a wire 82 to the wire 72 and having its other end connected to the wire 71.

The wire 69 is also connected to one end of a grid leak or bleeder resistor 83 (which may be of 20 megohms resistance), the other end of which resistor is joined by a wire 84 to a ground connection 85. The wire 72 is connected by a wire 86 to a resistor 87 (which may be of 600 ohms resistance), the said resistor being connected to a wire 88 joined with the control grid 89 of the vacuum tube 65, and being connected to a second resistor 90 (which may also be of 600 ohms resistance), the latter resistor being joined to a ground connection 91. Positive potential for the anodes 92 and 93 of the vacuum tubes 65 and 66 is supplied from a high voltage winding 94 of the power transformer 79, and the said winding may have a voltage of 115. The winding 94 has one end connected by a wire 95 to a ground connection 96 and has its other end connected by a wire 97 to a rectifier 98, which is in turn connected by a wire 99 to one end of which a pair of drop resistors 100 and 101 (which may be of 10,000 ohms resistance each), the other ends of said resistors being connected by wires 102 and 103 with screen grids 104 and 105 respectively of the vacuum tubes 65 and 66. A condenser 106 is connected between the wires 95 and 97 to smooth out the rectified output of the transformer winding 94.

The wires 102 and 103 in the anode circuits of

the vacuum tubes are connected by wires 107 and 108 through a connector fitting 109 to wires 110 and 111 respectively. The wires 110 and 111 connect to limit switches 112 and 113 respectively, the other terminals of said switches being connected by wires 114 and 115 to the clutch energization terminals 29 and 26 of the powered means 22. The limit switches 112 and 113 are normally closed as shown, and are arranged to be actuated by a cam 116 carried on the shaft 25 of the powered means when the shaft reaches its extremity of movement in one direction or the other. Actuation of either of the limit switches 112 and 113 opens the circuit of that one of the clutches of the powered means 22 which has been operative to drive the shaft 25 to its extremity of movement, and therefore, further turning force is removed from the said shaft.

The anodes 92 and 93 of the vacuum tubes 65 and 66 are connected by wires 117 and 118 to a manually operable rotary selector switch 119, which has wires 120 and 121 leading from it and connected through the connector fitting 109 with wires 122 and 123 which are respectively connected with the clutch terminals 27 and 28. When the selector switch 119 is in operative position for automatic operation of the control, indicated by "A" in Fig. 1, the wires 117 and 118 thereof are respectively connected with the wires 120 and 121.

The motor terminals 23 and 24 of the powered means 22 are connected by wires 124 and 125 through the connector fitting 109 respectively to the wires 126 and 127, the wire 126 leading to a pair of supply terminals 128 and the wire 127 leading to the selector switch 119. A wire 129 leads from the selector switch 119 to the other supply terminal of the pair 128. When the selector switch 119 is in position for automatic operation, the wires 127 and 129 are connected together, thereby effecting energization of the motor of the powered means 22 from the supply terminals 128.

Referring back to the energizing of the instrument relay 43, this energization is controlled by a slider contact 130 on the throttle resistor 51, the said contact being actuated by a throttle lever 131 which is movable over a graduated scale 132. The slider contact 130 is connected by a wire 133 with a contact 134 of a relay 135 having a cooperable contact 136 connected by a wire 137 with the wire 52. The contacts 134 and 136 of the relay 135 are normally closed, and the purpose of the relay itself will be disclosed later in detail.

Further control of the energization of the instrument relay 43 is exercised by the anticipator resistor 53, this resistor being in turn controlled by the movements of the powered means 22 by virtue of connections as follows:

The wire 54 connected to the resistor 53 is also connected by a wire 138 to the contact arm 38 actuated by the driving arm 32 on the shaft 25 of the powered means 22, and a wire 139 connects the wire 52 from the resistor 53 to the stationary contact 39 which is cooperable with the arm 38.

According to the above organization, when the supply terminals 81 and 128 are energized from suitable sources, the parts 20 and 21 of the control device will be in a state of oscillation or hunting, and upon the thermocouple 17 being heated in response to operation of the jet-turbine engine 10, the fuel valve 16 will be automatically controlled or regulated to maintain the engine

temperature within a predetermined range. This is accomplished as follows: Considering the rotary switch 119 as set for automatic operation, wherein the wires 129, 117 and 118 are respectively connected to the wires 127, 120 and 121, and assuming that the throttle lever 131 is set in a given position, and that the engine 10 is operating at a predetermined safe temperature, the thermocouple 17 will be heated and will cause an energization of the coil 44 of the instrument relay 43. If this energization is below a predetermined value, the movable contact 45 of the instrument relay 43 will engage the stationary contact 46 thereof, as shown in Fig. 1. Also, for safe operating temperatures of the engine 10 the movable contact 59 of the instrument relay 57 will be engaging the stationary contact 60 thereof as shown.

For the above conditions the contact arm 38 may initially be separated from the stationary contact 39, thereby enabling the anticipator resistor 53 to be operative in the energizing circuit for the coil 44 of the instrument relay 43. As a consequence of these positionings of the parts, the vacuum tube 66 will now be made operative, in the following manner: A circuit will be established between the cathodes 76 and 77 of the vacuum tubes 65 and 66, through the wire 72 and instrument relays 57 and 43 to the wire 69, and will cause the latter to assume the potential of the said cathode. Assuming that the ground potential is zero, and that the potential of the wire 29 from the high voltage coil 94 of the power transformer 79 is 115, and assuming that the vacuum tube 65 is conducting (i. e. passing an electron stream between its cathode and anode) a voltage drop will exist across the combined resistors 87 and 90 (due to the anode current passing therethrough) which may be in the neighborhood of 7 volts, and therefore, the polarity of the cathodes 76 and 77 with respect to ground will be approximately 7 volts. Due to the connection between the wire 69 and the cathodes as effected by the instrument relays 57 and 43, the polarity of the wire 69 with respect to ground will also be approximately 7 volts. As a consequence of the proportioning of the grid resistors 68 and 83, most of this 7 volt potential of the wire 69 will be impressed on the control grid 67 of the vacuum tube 66, and this relatively high positive potential, almost that of the cathode 77, together with the much higher potential on the anode 93 of the tube 66 will cause the latter to be conducting. This condition therefore results in energization of the clutch, of the powered means 22, which is connected with the terminals 28 and 29 and also causes a relatively high voltage drop across the resistor 109. Energization of the clutch connected with the terminals 28 and 29 causes clockwise rotation of the shaft 25, since the motor of the powered means 22 is being energized from the supply terminals 128. Immediately upon the shaft 25 starting its rotation the arm 32 carried thereby will be swung clockwise or to the left and will drive the contact arm 38 to the left so as to engage the stationary contact 39. This will immediately exclude the anticipator resistor 53 from the energizing circuit for the instrument relay 43, and will therefore cause immediate increase in the current passing through the coil 44.

The voltage drop across the resistor 109 will reduce considerably the potential on the screen grid 104 of the vacuum tube 65, such reduction being sufficient to stop the tube from being con-

ducting, that is, sufficient to not sustain the flow of electrons to the anode 92 of the tube from the cathode 76.

Preferably the amount of current increase caused by exclusion of the anticipator resistor 53 is equivalent to the current increase which would be caused by the temperature of the thermocouple 17 being raised approximately 400° F. The increase of current occasioned by exclusion of the anticipator resistor 53 results in the movable contact 45 of the instrument relay 43 being quickly swung to the right and separating from the stationary contact 46 thereof. Upon this occurring the potential impressed on the wire 69 by its connection through the instrument relays 43 and 57 with the cathodes 76 and 77 is removed, thereby immediately causing a reduction in the positive potential of the control grid 67.

The vacuum tube 66 now tends to become non-conducting since the positive potential of the control grid 67 thereof is insufficient to sustain in a stable condition the electron stream from the cathode 77 to the anode 93, and the said electron stream therefore becomes reduced. Reduction of said electron stream largely wipes out the voltage drop across the resistor 100 and therefore the wire 102 is charged with a relatively high positive potential which approaches in value that of the wire 99, the said potential being therefore applied to the screen grid 104 of the vacuum tube 65. This high potential on the screen grid 104, together with a positive potential (measured from ground) on the control grid 89 resulting from connection of the latter through the wire 88 to the common connection between the resistors 87 and 90 causes the vacuum tube 65 to again become conducting even though the grid 89 is slightly negative with respect to the cathode 76. The resulting anode current flowing in the wire 117 and through the resistor 101 results in a substantial voltage drop across the said resistor, thereby reducing substantially the potential on the screen grid 105 of the vacuum tube 66, and this results in the tube 66 being positively rendered non-conducting. The anode current flowing in the wire 117 passes through the clutch, of the powered means 22, which is connected with the terminals 26 and 27, thereby energizing the said clutch and resulting in the shaft 25 being rotated in a counterclockwise direction. Such rotation swings the arm 32 to the right, enabling the contact arm 38 of the anticipator device to separate from the stationary contact 39 thereof and causing the anticipator resistor to be included in the energizing circuit for the coil 44. Such inclusion of the anticipator resistor 53 results in a reduction of current in the equivalent coil 44 to a 400° F. change of temperature of the thermocouple 17, and therefore the contact arm 45 of the instrument relay 43 swings quickly to the left and again engages the stationary contact 46. Upon this occurring the cycle of operations described above is repeated and therefore the control device is in a continually hunting or oscillating state, and the capstan 30 is being rotated back and forth in step with the said oscillations, the movements of the capstan having relatively small magnitude. These movements are transmitted to the control valve 16, actuating the latter back and forth rapidly in step with the oscillations of the control device.

It will be seen that the anticipator device when actuated by the forward rotation of the powered

means 22 operates to cause reverse rotation thereof, and the said reverse rotation of the powered means 22 actuates the anticipator device so that the latter operates to again cause forward rotation of the powered means.

With the operation as described above a condition of balance is reached whereby the temperature of the jet-turbine engine 10 is maintained within a predetermined range approximately plus and minus 10° F. or less, the particular predetermined range being determined by the average of the values of the current flowing in the instrument relay coil 44 due to the E. M. F. of the thermocouple 17 and cutting in and out of the anticipator resistor 53, this average current value in turn being determined in part by the throttle resistor 51 in the thermocouple circuit.

For such condition of balance a predetermined relation will exist between, on the one hand, the temperature of the jet-turbine engine 10 and, on the other hand, the average energization of the instrument coil 44 (average of peak and low current values effected through inclusion and exclusion of the anticipator resistor 53), and the coil 44 will be energized on an average proportionately with the temperature of the engine. That is, for a condition of balance of the control device, if the engine temperature should increase for some reason the average current passing through the coil 44 will increase, and vice versa. Also, a predetermined relationship exists between the temperature of the engine 10 and the period of oscillation or hunting of the contact arm 45 of the instrument relay 43, and also the period of the other oscillating parts of the control device, inasmuch as the period of oscillation is also proportionate with the temperature of the engine 10. For example, if the temperature of the engine 10 should be increased by some circumstance not involved with a change of the setting of the control device, the coil 44 of the instrument relay 43 would receive more average current and produce greater reactions on the instrument field, and consequently the movements of the contact arm 45 thereof to the right or away from the stationary contact 46 would have a greater magnitude. Due to the inertia of the contact arm and damping thereof, this would accordingly result in the period of oscillation being increased, and in the same manner the period will be decreased if through some circumstance the temperature of the engine 10 were reduced. Of course, a rise in the temperature of the engine 10 and an increase in the period of oscillation of the contact arm 45 would result in the said arm being out of engagement with the stationary contact 46 for longer intervals of time, and therefore the capstan 30 of the powered means 22 would be caused to creep in one direction i. e., counterclockwise, thereby resulting in a closing of the fuel control valve 16, and this will in turn result in the temperature of the engine being reduced. By this action the temperature of the engine is automatically held within a predetermined range.

From the above it is seen that the amplitude of oscillation of the contact arm 45 of the instrument relay 43, and of the other oscillating parts of the control device are proportionate with the temperature of the engine 10, and for a given setting of the control device, this amplitude has a predetermined relationship to the said temperature. Also, it will be understood that the oscillation of the contact arm 45 is caused by the application of a uni-directional fluctuating

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deflecting force to the said arm through the medium of the coil 44, and that the average magnitude of the said deflecting force is proportionate with the temperature of the engine 10. The contact arm 45 is in fact a deflectable member and is biased by means of the usual spiral coil springs commonly employed in instrument movements, though no such coil springs are shown in the drawing since their construction and operation are well-known and understood.

During normal operation of the control device, at all times when a state of balance is reached, the average energization of the coil 44 and average deflecting force on the coil and on the contact arm 45, and the amplitude and period of oscillation of the coil and arm, and of the shaft 25 and capstan 30 of the device will be within related predetermined narrow fixed ranges.

If now the throttle lever 131 is shifted downward, as viewed in Fig. 1, toward its closed position, less resistance will be included in the thermocouple circuit, and the average current passing through the coil 44 will be increased. This will upset the state of balance of the control, and when balance is again established, will result in a new relationship between the temperature of the engine 10, on the one hand, and on the other hand the normally constant factors including the average energization of the coil 44 and period of oscillation of the contact arm 45 and of the other oscillating parts of the control device. The new relationship will be characterized by a new and lower value of temperature and speed or power of the engine 10, and will be effected through closing of the fuel valve 16 in the following manner: Upon the throttle lever 131 being shifted downward, as stated above, the said normal state of balance is disturbed, and due to the increased average current flowing through the coil 44 the impulses transmitted to the coil and to the contact arm 45 will be of greater magnitude, and consequently the amplitude of oscillation of the contact arm 45 will be greater. This will result in the intervals of operation of the vacuum tube 65 being longer than the intervals of operation of the vacuum tube 66, and will cause the shaft 25 and capstan 30 of the powered means 22 to creep in a counterclockwise direction, thereby closing the fuel control valve 16 and reducing the temperature and speed of the engine 10. When the temperature of the engine 10 has been sufficiently reduced so that the period of oscillation of the control device has returned to its fixed range, which is normally constant, a state of balance again will have been reached and the engine temperature and power will therefore be maintained at the new lower value, or to be more exact, within a lower range which in practice has a total spread somewhat less than 20° F.

Stated another way, the closing of the throttle lever 131 (moving it downward) increases the length of the intervals of disengagement of the contact arm 45 and stationary contact 46, and increases the length of the intervals of inclusion of the anticipator resistor 53 in the circuit of the relay coil 44, this being due to the increase in the average force on, or driving the contact arm 45.

Conversely, if the throttle lever 131 should be shifted upward toward its open position, as viewed in Fig. 1, more resistance will be included in the thermocouple circuit for the instrument relay 43 and the coil 44 thereof will have its average current reduced. This again

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will alter the relationship between the temperature of the engine 10 on the one hand and on the other hand the average energization of the coil 44, and the amplitude and period of oscillation of the contact arm 45. The arm 45 and coil 44 will now have a weaker fluctuating force transmitted to them, and the amplitude of oscillation will be decreased and the period decreased.

In consequence of this the intervals of operation of the tube 66 will be longer than the intervals of operation of the vacuum tube 65, therefore the shaft 25 and capstan 30 of the powered means 22 will be caused to creep in a clockwise direction thus opening the fuel control valve 16. This in turn will cause more fuel to be delivered to the engine 10 and will increase the temperature and power of the latter, and such increase will continue until a state of balance is again reached wherein the period of oscillation of the control device has returned to its normal fixed value. Thus an automatic control of engine temperature and power is had whereby these variables may be maintained in any selected one of a plurality of different predetermined ranges as determined by the setting of the throttle lever 131.

It will be seen that the powered means 22 is actuated either forwardly or in reverse direction according to whether the magnitude and period of oscillation of the contact arm 45 is greater or less than a predetermined value which corresponds with the predetermined fixed period of oscillation obtained when the control device is in a state of balance.

By providing the graduations 132 for the throttle lever 131, and by affixing proper values to the graduations, the setting of the throttle lever will be indicative of the temperature of the engine 10 within for example, approximately plus or minus 10° F.

The oscillating control device of this invention as described above provides for rapid response to changes in the temperature of the engine 10 or the setting of the throttle lever 131 and therefore a close regulation is had which minimizes the possibility of engine racing or temperature overshooting or reaching an excessive, dangerous value at any time. For example, a time lag of approximately 15 seconds exists between a change in the temperature of the engine 10 and the response of the thermocouple 17 to the said change. However, by the provision of the anticipator device by which the control is made to have a rapid rate of oscillation the overall response time of the control, or time required to establish a given engine temperature, is reduced to about 2 seconds, and this is effected as follows. If the throttle lever 131 is shifted upward toward open position, thereby increasing the resistance in the thermocouple circuit connected to the instrument relay 43, an immediate decrease in the average current flowing in the coil 44 of the relay will occur, and if the anticipator device comprising the resistor 53 and cooperable contacts 38 and 39 controlling the said resistor were omitted, the contact arm 45 of the instrument relay 43 would rest for a relatively long interval of time against the stationary contact 46, and this would result in a long interval of operation of the vacuum tube 66 and cause a considerable clockwise rotation of the capstan 30, thereby opening the fuel valve 16 by a substantial amount. This in turn would feed a great deal of fuel to the engine 10 and would result in an excessive temperature and power thereof, and such temperature and power

would not be immediately checked, due to the slow response of the thermocouple 17. However, by the provision of the anticipator device, immediately upon the contact arm 45 engaging the stationary contact 46 in the instrument relay 43, the initiation of movement of the capstan 30 by such engagement will cause the contact arm 38 of the anticipator to engage the stationary contact 39 thereof, thereby shorting-out the anticipator resistor 53 and resulting in a substantial increase of current through the coil 44. This substantial increase in current immediately drives the contact arm 45 of the instrument relay away from its cooperable contact 46, and the above will be repeated continually; therefore a condition will not exist where the fuel valve 16 is initially opened a substantial and excessive amount. Instead, the valve 16 is caused to have a delayed action, so to speak, which approaches the delayed action or lag of the thermocouple 17 and offsets the effect of the latter, and therefore overshooting of the engine temperature is effectively prevented, and an engine response and reestablishment of a condition of balance is obtained in response to a change in the throttle setting 131 which is on the order of 2 seconds in spite of the 15 second time lag of the thermocouple 17.

It will be noted that the action of the anticipator device comprising the resistor 53 and contacts 38 and 39 controlling the said resistor is to continually and rapidly change an unvarying relationship which, if the anticipator device were omitted, would exist between on the one hand the temperature of the engine 10 and on the other hand the energization of the coil 44, thereby to provide a fluctuating energization of said coil. When the anticipator resistor 53 is included in the circuit it results in a change approximately equal to a 400° F. change of temperature of the thermocouple 17 as above mentioned.

The inclusion of the resistor 53 in the circuit of the coil 44 alters the relationship which exists between energization and deflection of the coil and the temperature of the engine 10 when the anticipator contacts 38 and 39 are engaged and the resistor is short-circuited. Such inclusion of the resistor 53, effected by small closing movement of the valve 16, causes an actuation of the powered means 22 in the same sense as and prior to the actuation it would normally have in responding to a drop in temperature of the engine 10 caused by a greater closing movement of the valve 16.

The net effect of the anticipator means comprising the resistor and contacts 38 and 39 is thus to decrease the period of hunting or oscillation of the control device, that is, to make it oscillate or hunt at a much more rapid rate than that which it would normally have if the anticipator mechanism were not provided. For such event the control device would hunt at a relatively slow rate, and the temperature of the engine 10 would fluctuate between relatively wide limits due to the time lag of the thermocouple 17.

However, the anticipator device considerably reduces or narrows the range within which the engine 10 is maintained, and makes for a much more accurate control and one which is more quickly responsive and maintains engine temperatures within safe limits.

If the control device should be so operated that the valve 16 is driven to one extreme or the other of its movement by the capstan 30 the cam 116

is so arranged that it will actuate one or the other of the limit switches 112, 113, the said switches opening the circuit of the clutch which is being operated to drive the capstan toward the said limiting position, and therefore driving force is removed from the capstan, preventing damage to the mechanical driving system involving the fuel valve 16 and the capstan and also the clutch of the powered means 22. The limit switches 112 and 113 do not interfere with return movement of the capstan 30 from the said limiting position but merely relieve the capstan of its driving force when it is at said position, and normally when a limit switch is operating it renders ineffective that part of the operating cycle of the contact arm 45 which tends to advance the capstan 30 beyond the limiting position thereof, the limit switch however supporting the oscillation of the control device in much the same manner as the contact arm 45 supports the said oscillation.

The instrument relay 57 has its stationary contact 60 so adjusted that the contact arm 59 will be disengaged therefrom only upon the movable coil 58 being energized with a relatively heavy current, corresponding to a dangerously high temperature of the thermocouple 17 and engine 10. Therefore, when the engine reaches such a dangerously high temperature the circuit between the wires 72 and 69 will be automatically opened, and the vacuum tube 65 automatically made conducting thereby to cause operation of the clutch of the powered means 22 connected with the terminals 26 and 27 to cause counterclockwise rotation of the shaft 25 and to close the fuel valve 16. This, therefore, is a safety device by which excessive temperatures of the engine 10, which might damage the engine, are automatically prevented. If the engine should approach such excessive heating and should thereafter become cooled to a safer temperature the response of the thermocouple 17 will enable the contact arm 59 of the instrument relay 57 to again engage the stationary contact 60 thereof whereupon the automatic control of the engine temperature is reestablished through functioning of the instrument relay 43.

While the blocking relay unit 56 comprising the vacuum tubes 65 and 66 is shown as having both screen grids connected for blocking purposes, the connection to the screen grid 105 of the tube 66 may be omitted and the circuit constants altered to obtain a suitable alternate operation of the tubes.

The rotary selector switch 119 is so arranged that it may be shifted to an off position, as indicated, whereupon the wires 129, 117 and 118 are respectively disconnected from the wires 127, 120 and 121, in which event the automatic control over the engine temperature is discontinued. For such setting of the switch 119 the fuel valve 16 will remain in the position it occupied at the time that the switch was shifted to off position.

Means are also provided under the control of the selector switch 119 for manually regulating the fuel valve 16 without benefit of automatic regulation. This means comprises a pair of push button switches 140 and 141 which are operable by means of push buttons 142 and 143 respectively.

The switch 140 is a double pole single throw switch normally biased to open position and comprises a pair of blade contact arms 144 and 145 which are insulated from each other and are actuated by operation of the push button 142.

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For cooperation with the movable blades 144 and 145 stationary contact blades 146 and 147 are provided. The switch 141 is also a double pole single throw switch normally biased to open position, and comprises a pair of movable contact blades 148 and 149 insulated from each other and actuated by operation of the push button 143. For cooperation with the blades 148 and 149 stationary contact blades 150 and 151 are provided.

Connections for the switches 140 and 141 are as follows: The contact blade 146 is connected by a wire 152 with the contact blade 148, and the said wire 152 is connected by a wire 153 with the wire 129 of the control device. The contact blade 147 is connected by a wire 154 with the contact blade 151, and the wire 154 is connected by means of a resistor 155 (which may be of approximately 10,000 ohms resistance), to a ground connection 156. The contact blade 144 is connected by a wire 157 to the contact blade 150, and the latter is connected by a wire 158 with the selector switch 119 so that when the selector switch is in manual position the wire 158 is connected to the wire 127. The contact blades 145 and 149 are respectively connected by wires 159 and 160 with the selector switch 119 so that when the latter is in manual position the wires 159 and 160 will be respectively connected with the wires 120 and 121.

When the selector switch 119 is in manual position the wires 129 and 117 and 118 are disconnected from the wires 127, 120, 121 respectively so that automatic control of the engine is not had. Also for this setting of the selector switch 119 if the push button 142 is depressed the clutch of the powered means 22 connected with the terminals 26 and 27 is energized from the high voltage coil 94 of the power transformer 79 through the resistors 155 and 101, and the shaft 25 and capstan 30 of the powered means 22 is caused to rotate in a counterclockwise direction, closing the valve 16. If the push button 143 is depressed, the clutch of the powered means 22 which is connected with the terminals 128 and 129 is energized through the resistors 155 and 100 from the high voltage winding 94 of the transformer 79 and the shaft 25 and capstan 30 are caused to rotate in a clockwise direction, opening the valve 16.

For such manual operation of the valve 16 the anticipator mechanism comprising the anticipator resistor 53 and contacts 38 and 39 of course do not have any effect on the actuation of the valve.

For the purpose of indicating whether or not the motor of the powered means 22 is energized, an indicator light 161 is provided, connected by a wire 162 with the wire 124, and by a wire 163 with the wire 125.

In accordance with the invention means are provided in conjunction with the oscillating control device whereby the effect, on the engine 10, of conditions such as sudden diving or steep climbing of the aircraft is automatically minimized, by immediately supplying the engine with either less fuel or more fuel respectively, this being done during the brief interval in which the change in the speed of the aircraft is occurring. That is, if the aircraft should suddenly be thrown into a steep climb, the engine 10 will automatically immediately be fed more fuel, before the pilot of the craft can respond to the climb by advancing the throttle. Also, if the aircraft should be thrown into a sudden dive, the fuel to the engine 10 will be immediately automatically

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decreased, and this will occur before the pilot has time to decrease the throttle setting. Such sudden changes of the aircraft may be occasioned, for instance, by airpockets or bumpy air conditions.

Accordingly, referring to Fig. 1, a relay 164 is provided having contacts 165 and 166 respectively connected by wires 167 and 168 to the wire 50 and contact arm 130 of the throttle resistor 51. The contacts 165 and 166 are normally open, and therefore the functioning of the throttle resistor 51 is normally not altered. The relay 164 has a coil 169 connected by a wire 170 with a coil 171 of the relay 135, and the wire 170 is connected to one terminal of a D. C. generator 172 which is coupled to be driven from the driving shaft 14 of the engine 10, as indicated by the broken line 173. The other terminal of the generator 172 is connected to a condenser 174 whose other terminal is connected to a wire 175 the ends of which are connected respectively to rectifier units 176 and 177. The rectifier 176 is connected by a wire 178 with the relay coil 169, and the rectifier 177 is connected by a wire 179 with the relay coil 171. The rectifier 176 is arranged to enable current to flow through it from the wire 178 to the wire 175, and to prevent current from flowing through it from the wire 175 to the wire 178. The rectifier 177 is arranged to enable current to flow through it from the wire 175 to the wire 179 and to prevent current from flowing through it from the wire 175 to the wire 179.

In conjunction with this organization the propeller 15 of the aircraft is preferably chosen to be of the variable pitch type, and the pitch of the propeller is adjusted in conjunction with shifting of the throttle lever 131 so that the driving shaft 14 of the motor 10 has a substantially constant speed for different throttle settings and different fuel inputs to the engine.

The operation of this automatic control responsive to sudden climbing or diving of the aircraft is as follows: During normal flight conditions of the craft, the engine shaft 14 will be rotating at a substantial constant speed and the output of the D. C. generator will have a fixed and unvarying value. For such value no current will be caused to flow in either of the relay coils 169 or 171. If however the aircraft should be caused to suddenly dive, as by an atmospheric condition, the engine shaft 14 will suddenly increase its speed, and this will increase the output voltage of the generator 172 and cause a current to flow through the generator 172, relay coil 169 and rectifier 176, and through the condenser 174. Such current will only continue to flow as long as an acceleration of the engine shaft 14 and generator 172 takes place. Energization of the relay 164 caused by such current will close the relay contacts and result in the throttle resistor 51 being short-circuited, thereby increasing the current through the instrument relay coil 44 and causing the contact arm 45 thereof to separate from the stationary contact 46. This will immediately render inoperative the vacuum tube 66 and cause the vacuum tube 65 to become operative, with the result that the powered means 22 will be caused to operate in a counterclockwise direction, thereby partly closing the fuel valve 16 and reducing the fuel supply to the engine 10. As soon as acceleration of the engine shaft 14 and generator 172 ceases, the relay 164 will be de-energized due to the condenser 174 becoming

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fully charged and not passing any more current.

A similar action occurs if the aircraft should suddenly be made to climb, as by an atmospheric condition, since deceleration of the engine shaft 14 will cause a drop in voltage at the terminals of the generator 172, which will result in current flowing through the relay coil 171, rectifier 177 and condenser 174 by discharge of the latter. Such current will open the contacts of the relay 135 and cause the full resistance value of the throttle resistor 51 to be included in the thermocouple circuit, thereby reducing the energization of the coil 44 and causing the contact arm 45 of the instrument relay to remain in engagement with the stationary contact 46. This will cause the vacuum tube 66 to become operative and will actuate the powered means 22 in a clockwise direction, opening the fuel valve 16 and increasing the fuel supply to the engine 10 automatically.

It will be noted that the quick automatic increase and decrease of flow of fuel to the engine 10 in response to climbing or diving of the aircraft is effective only during deceleration and acceleration of the engine shaft 14, and as soon as such change in speed of rotation ceases the automatic compensation for the change ceases. This organization is therefore operative before the pilot of the aircraft has time to readjust the setting of the throttle 131, and by the time the automatic compensation ceases to operate the pilot will have been able to properly reset the throttle 131 if this should be necessary. Often it will not be necessary due to the altered flight conditions of the aircraft being only temporary.

Another form of invention is illustrated in Fig. 2. In this figure parts which correspond to parts in Fig. 1 have been given the same characters, generally. The operation of this form of the invention is in many respects similar to the operation of the form shown in Fig. 1, and in general the following structural differences exist between the two forms of the invention: Instead of the pair of vacuum tubes 65 and 66, the device of Fig. 2 employs but a single vacuum tube, and employs mechanical relays which are not of the sensitive-instrument type. A second sensitive-instrument relay for safeguarding the engine against extremely high temperatures is not shown in the device of Fig. 2, although it may be incorporated therein in the same manner as in the device of Fig. 1. Instead of a single anticipator resistor as shown in Fig. 1, the device of Fig. 2 incorporates two anticipator resistors, one controlled by the powered means of the device and the other controlled by the above mentioned mechanical relays. Finally, a slightly different form of powered means for actuating the fuel control valve of the engine is illustrated.

Referring to Fig. 2, propeller 15 of the jet-turbine engine 10 is shown in full lines, the engine 10 being shown in block outline for the sake of simplicity of illustration. Responsive to the heating of the engine 10 is the thermocouple 17 which is shown in schematic representation.

The powered means for driving the fuel valve 16 which controls the fuel supply to the engine 10 is shown as comprising an electric motor 184 having an armature 185 and a field 186, the armature shaft carrying a pulley 187 over which a belt 188 passes. The belt 188 is guided by idler pulleys 189 and 190 and passes over

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pulleys 191 and 192 which are loosely carried on a shaft 193. The belt 188 also passes over a third idler pulley 194 by which it is enabled to drive the pulleys 191 and 192 in opposite directions. A clutch plate 195 is fixedly mounted on a shaft 193 between the pulleys 191 and 192 and is cooperable with clutch facings 196 and 197 whereby the shaft 193 may be driven in one direction or the other upon its being axially shifted to either of two positions.

Axial shifting of the shaft 193 is accomplished by a forked arm 198 engageable with collars 199 and 200 on the shaft 193. The arm 198 carries a magnetic armature piece 201 which is subjected to magnetic attraction from a core 202 energized by a magnet coil 203. An extension spring 204 connects the arm 198 with a stationary anchorage 205 and normally holds the armature piece 201 away from the core 202 when the latter is not magnetized.

The shaft 193 carries a pinion 206 meshing with a gear wheel 207 mounted on and driving shaft 25 which carries the capstan 30 and which is mechanically connected to drive the fuel valve 16.

The anticipator device comprises arm 32 which is frictionally carried by the shaft 25 and is engageable with abutment 41 and with switch arm 38 to actuate the latter. The switch arm 38 is engageable with the abutment or stop 40 and with the stationary contact 39. The contact arm 38 and stationary contact 39 are connected respectively by wires 208 and 209 through a connector fitting 210 with wires 211 and 212, the latter wire being connected to one end of an anticipator resistor 213. Also, a second anticipator resistor 214 is provided, connected by a wire 215 to the wire 208 and by a wire 216 to the wire 209.

In Fig. 2 the throttling control and automatic safety control responsive to sudden climb and diving of the aircraft are blocked off by a broken rectangular outline 217, and the parts illustrated within said outline are numbered similarly to corresponding parts in Fig. 1, and function similarly thereto.

The thermocouple 17 is connected by a wire 218 with the movable coil 219 of a sensitive instrument relay 220 which is in general similar to the relays 43 and 57, the other end of the coil 219 being connected through a resistor 221 to a wire 222 which connects through a connector fitting 223 and a wire 224 to one end of the throttle resistor 51. The remaining terminal of the thermocouple 17 is connected by a wire 225 through the fitting 223 with the wire 211.

The instrument relay 220 has a contact arm 226 which is cooperable with a stationary contact 227, the latter being connected through a resistor 228 (which may be of one megohm resistance) to a wire 229 which in turn connects to one end of a grid resistor 230 (which may be of approximately three megohms resistance) the other end of said resistor 230 being connected with the control grid 231 of a screen grid vacuum tube 232. The contact arm 226 of the instrument relay is connected by a wire 233 with one end of the heater 234 of the vacuum tube 232 (which may be of type 9003, the other end of the said heater being connected with the cathode 235 of the vacuum tube and the cathode being connected to one end of a resistor 236 (which may be of approximately thirty ohms resistance). The other end of the resistor 236 is connected to a wire 237 which connects with a grid leak 238 and grid condenser 239 the other ends of which are connected to the wire

229. The leak 238 and condenser 239 may be of twenty megohms resistance and .001 mfd. capacity respectively.

Energization of the device of Fig. 2 is supplied by a battery 240 which may have a voltage of 24, the negative terminal of which battery is connected to a negative line wire 241 in turn connected with the wire 237. The positive terminal of the battery 240 is connected by a wire 242 with a multi-pole selector switch 243 having three positions as indicated, "off," "M" (for manual operation) and "A" (for automatic operation of the device). When the selector switch 243 is set for automatic operation the positive supply wire 242 thereof is connected with a wire 244 leading from the switch and through the connector fitting 223 for connection with a wire 245 which is in turn connected to one end of the coil 246 of a relay 247, the other end of the coil being connected by a wire 248 with the anode 249 of the vacuum tube 232. The relay coil 247 is bridged by a condenser 250 to prevent its chattering.

The screen grid 251 of the vacuum tube 232 is connected by a wire 252 with a resistor 253 (which may be of 100 ohms resistance), the said resistor being also connected by a wire 254 with the wire 233.

The relay 247 has an armature contact 255 connected by a wire 256 with the wires 245 and 252, said relay controlling the energization of three relays 257, 258 and 259, and for this purpose the coils 260, 261 and 262 of the said three relays are connected in parallel by wires 263 and 264, and the wire 263 is connected by a wire 265 through the connector fitting 223 to a wire 266 which connects with the stationary contact 267 of the relay 247. The wire 264 connected with the relay coils 260, 261 and 262 is energized through connection with a wire 268 which is connected with the negative supply wire 241.

For the automatic setting of the selector switch 243 the wire 244 thereof is connected to wires 269 and 270, the wire 269 being connected through a connector fitting 271 with a wire 272 leading to the armature 185 of the motor 184. The other terminal of the armature 185 is connected by a wire 273 through the connector fitting 271 to a wire 274 which leads to the selector switch 243 and which, when the switch is in automatic setting, is connected with a wire 275 in turn connected through the fitting 271 with a wire 276 joining to one end of the motor field 186. The other end of the motor field is connected by a wire 277 through the fitting 271 with the negative supply wire 241 of the circuit.

The wire 270 leading from the selector switch 243 connects with a resistor 278 (which may be of 10 ohms resistance), the said resistor being connected by a wire 279 through the fitting 271 to a wire 280 which connects with a normally-closed limit switch 281, the said switch being also connected by a wire 282 with the magnet coil 203 for actuating the reversing clutch system of the capstan drive. The limit switch 281 is actuated by cam 116 on the capstan shaft 25, the switch being opened when the capstan 30 and valve 16 approach a limit of movement. The other end of the magnet coil 203 is connected by a wire 283 through the fitting 271 to a wire 284 which connects with a contact 285 of the relay 258. The other contact 286 of the relay 258 is connected by a wire 287 with a contact 288 of the relay 257, and the cooperable contact 289 of said relay is connected by a wire 290 with the wire 264.

Sparking of the contacts of the relays 257 and 258 is reduced by a resistor 291 and condenser 292 connected with the wires 264 and 284, and sparking at the contacts 255 and 267 of the relay 247 is reduced by a resistor 182 and condenser 183 connected across said contacts.

The anticipator circuit of the device is completed by wires 293 and 294 which connect the ends of the anticipator resistor 213 respectively with contacts 295 and 296 of the relay 259, and the relay contact 295 is also connected by a wire 297 with the wire 137.

Considering the capstan 30, a second limit switch 298, which is normally opened, is located for actuation by the cam 116 when valve 16 reaches the other limit of movement. The limit switch 298 is connected by a wire 299 through the connector fitting 271 with the negative supply wire 241 of the circuit, and the switch 298 is also connected by a wire 300 to the wire 283.

Arcing of the contacts of the limit switch 281 is minimized by a series connected resistor 301 and condenser 302 which are respectively connected by wires 303 and 304 with the wires 280 and 282.

A signal lamp 305 is connected to the wire 275, and is connected through a resistor 306 with the negative supply wire 241, thereby to indicate when the motor 184 is being energized.

Operation of the device of Fig. 2, with the selector switch 243 set in automatic position, is as follows: Assuming that the engine 10 is running, and that the thermocouple 17 is heated by the engine, and assuming that the vacuum tube 232 has been suitably warmed up, and with the contact arm 226 of the instrument relay 220 in the position shown (disengaged from the stationary contact 227), the vacuum tube 232 will be in a non-conducting condition. This is because the control grid 231 of the tube is negative with respect to the cathode 235, since the control grid is connected through the grid leak and resistor to the negative line wire 241 whereas the cathode is connected between the heater 234 and drop resistor 236 so as to have a positive potential with respect to the negative wire 241, equivalent to the voltage drop across the resistor. By virtue of this, the relay 247 will be deenergized and the contacts 255 and 267 will be in engagement as shown. This will cause the three relays 257, 258 and 259 to be energized. The contacts of the relays 257 and 258 will be closed, thereby to establish a circuit from the negative side of the battery 240 through the contacts and wires 284 and 283 to the magnet coil 203, and the said coil will be energized by virtue of its connection through the wire 282, limit switch 281 and wire 280, and through the wire 279, resistor 278 and wire 270 to the positive supply wire 242 from the battery, the connection between the wires 270 and 242 being effected through the selector switch 243. Energization of the magnet coil 203 will cause the clutch disk 195 to engage the clutch facing 197, thereby to rotate the shafts 193 and 25 so as to close the fuel valve 16, the rotation of the shaft 25 being in a counterclockwise direction for effecting this, as viewed in connection with the driving arm 32 which operates the anticipator switch arm 38. An open condition of the anticipator switch contacts 38 and 39 will cause the anticipator resistor 214 to be included in the circuit by which the instrument relay coil 219 is energized. Also energization of the relay 259 will cause the contacts thereof to be opened, thereby causing the second anticipator resistor

213 to be included in the energizing circuit for the instrument relay 219. The result of inclusion of these two anticipator resistors 213 and 214 in the energizing circuit for the instrument relay coil 219 will result in a sharp decrease in the current passing through the coil, and such decrease will cause the deflection of the coil and the contact arm 226 controlled thereby to decrease, thereby resulting in engagement of the contact arm 226 and stationary contact 227. Such action will immediately produce a positive potential on the control grid 231 of the vacuum tube 232, inasmuch as the wire 233 has a positive potential approximately to equivalent of the voltage drop existing across the resistor 246 and heater 234. The vacuum tube 232 therefore becomes operative, causing energization of the relay 247 and deenergization of the three relays 257, 258 and 259. This in turn cause deenergization of the magnet coil 203, and results in the clutch disk 195 being shifted out of engagement with the facing 197 and into engagement with the facing 196. This reverses the rotation of the shafts 193 and 25, the latter now rotating clockwise and opening the valve 16 and causing the driving arm 32 to actuate the anticipator switch arm 38 and cause the latter to engage the stationary contact 39 of the switch. Closing of the anticipator switch contacts and deenergization of the relay 259 causes a short-circuiting of the anticipator resistors 214 and 213, and results in an immediate substantial increase in the energization of the coil 219 of the instrument relay 220. The above cycle of operations is continually repeated, the device thereby being in a state of oscillation or hunting, in a manner similar to the device of Fig. 1, and a state of balance is reached whereby the position of the slider contact 130 on the throttle resistor 51 is the controlling factor in the temperature and speed of the engine 10. As in the case of the device of Fig. 1, the period of oscillation and magnitude of movement of the oscillating parts, for a given position of the throttle lever 131, will have a given predetermined relation to the temperature of the engine 10, and changes in the setting of the throttle lever 131 will change this relation. Such change will at first be reflected in a change in the period and magnitude of oscillation of the components of the control device, the said period and magnitude of oscillation gradually returning to its predetermined value however as the temperature and speed of the engine 10 are altered, and the changed relation ultimately will therefore be due solely to a change in the temperature and speed in the engine.

When the selector switch 243 is in the "off" position, the wires 242, 274, 269 and 270 connected therewith are left open-circuited, and since the wire 242 is the sole positive supply line of the circuit, the entire control device will be rendered inoperative and the fuel valve 16 will remain in the position it had when the selector switch was switched to "off" position.

For manual operation of the control device a pair of push button switches 307 and 308 is provided. The switch 307 has movable contact arms 309 and 310 which are normally engaged with stationary contacts 311 and 312 respectively, and which may be spread apart by depressing the manually operable button 313 so as to cause them to respectively engage stationary contacts 314 and 315. The switch 308 has a pair of contact arms 316 and 317 which are normally respectively engaged with stationary contacts 318

and 319 and which may be spread apart by depressing a manually operable button 320 to cause them to respectively engage stationary contacts 321 and 322. Contacts 315 and 318 of the switch are connected by a wire 323, contacts 312 and 322 connected together by a wire 324, contacts 314 and 319 connected together by a wire 325, and contacts 311 and 321 connected by a wire 326. The contacts 309 and 317 are connected by wires 327 and 328 to the selector switch 243 so that when the latter is set for manual operation these wires will be respectively connected with the wires 242 and 269. The contact 316 of the switch 308 is connected by a wire 329 with the selector switch 243 so as to be connected with the wire 274 when the switch is in manual operation. For such position of the switch, automatic operation of the magnet coil 203 will be prevented by virtue of the fact that the wire 270 leading from the switch is not connected with the positive side of the battery, due to the switch open-circuiting the said wire; the wire 270 is depended on by the magnet coil 203 for its positive connection with the battery 240. Instead, the clutch disk 195 will be held by the extension spring 204 in engagement with the clutch facing 196 continuously, and the motor 184 may be energized for rotation in one direction or the other by depressing one or the other of the buttons 313 and 320 of the pair of switches 307 and 308, the said switches acting as motor reversing switches as may be seen by following out these circuits.

While the control device of the present invention is applied to a jet-turbine engine to control the temperature thereof, it should be understood that the device may be applied to other instrumentalities or variables to control the values thereof, the intended scope of the invention being defined in the appended claims.

Variations and modifications may be made within the scope of this invention and portions of the improvements may be used without others.

I claim:

1. The method of maintaining within a predetermined range a variable regulated by a reversible control, which includes the steps of applying to a biased deflectable member a uni-directional fluctuating deflecting force of an average magnitude proportionate with the value of the variable to cause oscillation of the member, and operating said reversible control in one direction or the other according to whether the magnitude of oscillation of the member is greater or less than a predetermined value corresponding to the said predetermined range of the variable.

2. The method of maintaining within a predetermined range a variable regulated by a reversible control, which includes the steps of automatically applying to a biased deflectable member when and only when the latter is in a predetermined position of low deflection, a deflecting force of a magnitude proportionate with the value of the variable to cause oscillation of the member, automatically operating said control in one direction whenever the member is out of said predetermined position, and operating the control in the other direction whenever the member is in said predetermined position.

3. The method of maintaining a variable within a predetermined range by a reversible control, which includes the steps of continually moving a member away from and back to a predetermined fixed position to have a magnitude of

movement proportionate with the value of the variable, and oscillating said control to shift the center point of its movement in one direction or in the other according to whether the magnitude of movement of the member is greater or less than a predetermined value corresponding to the said predetermined range of the variable.

4. The method of maintaining a variable within a predetermined range by a reversible control, which includes the steps of continually moving a member back and forth between retracted and advanced positions to have a magnitude of movement proportionate with the value of the variable, and automatically operating said control in one direction or the other according to whether the magnitude of movement of the member is greater or less than a predetermined value corresponding to the said predetermined range of the variable; and manually varying the magnitude of movement of said member to affect a selection of a new predetermined range for said variable.

5. The method of maintaining within a predetermined range a variable regulated by a reversible control, which includes the steps of continually moving a member back and forth between a predetermined retracted position and advanced positions with a magnitude of movement proportionate with the value of the variable, and moving said control in one direction or the other according to whether the member is respectively in or out of said retracted position, the control being moved more in one direction than in the other when the magnitude of movement of the member is greater than a predetermined value, and being moved less in one direction than in the other when the magnitude of movement of the member is less than a predetermined value.

6. The method of maintaining a variable within a predetermined range by a reversible control, which includes the steps of producing in a force-transmitting medium a uni-directional force having a magnitude proportionate with the value of the variable, periodically altering the effectiveness of the force so as to provide oscillations in said medium having a period proportionate with the value of the variable, and automatically operating the control in one direction or the other in response to the period of the oscillations being greater or less than a predetermined value corresponding to said predetermined range of the variable.

7. The method of maintaining a variable within a predetermined range by a reversible control, which includes the steps of producing in a force-transmitting medium a uni-directional force having a magnitude proportionate with the value of the variable, periodically altering the effectiveness of the force so as to provide oscillations in said medium having a period proportionate with the value of the variable, automatically operating the control in one direction or the other in response to the period of the oscillations being greater or less than a predetermined value corresponding to said predetermined range of the variable, and manually altering the effectiveness of the force to select a new predetermined range for the variable.

8. The method of maintaining within a predetermined range a variable regulated by a reversible control, which includes the steps of producing in a force-transmitting medium a uni-directional force having a magnitude proportionate with the value of the variable, periodically

altering the effectiveness of the force so as to provide pulsations in said medium having a period proportionate with the value of the variable, and oscillating the control to shift the center point of its movement in one direction or the other according to whether the period of the pulsations is greater or less than a predetermined value corresponding to said predetermined range of the variable.

9. In a propelled device, the method of maintaining within a predetermined temperature range a jet-turbine engine regulated by a reversibly-operable fuel valve, which includes the steps of producing in a force-transmitting medium a uni-directional force having a magnitude proportionate with the temperature of the engine, periodically altering the effectiveness of the force so as to provide pulsations in said medium having a period proportionate with the temperature of the engine, and oscillating the fuel valve to shift the center point of its movement in one direction or the other according to whether the period of pulsations is greater or less than a predetermined value corresponding to the said temperature range.

10. In an aircraft, the method of maintaining within any selected one of a plurality of different predetermined temperature ranges a jet-turbine engine regulated by a reversibly operable fuel valve, which includes the steps of producing in a force-transmitting medium a uni-directional force having a magnitude proportionate with the temperature of the engine and in predetermined relation thereto, periodically altering the effectiveness of the force so as to provide oscillations in said medium having a period proportionate with the temperature of the engine, operating the fuel valve in one direction or the other according to whether the period of oscillations is greater or less than a predetermined value, and altering the relation between the period of oscillations and temperature of the engine to select the temperature range the engine is to be maintained in.

11. Apparatus for maintaining the temperature of an engine within a desired range, comprising a fuel control valve; means for rapidly moving the fuel valve by minute equal amounts in opening and closing direction while the engine is at the desired temperature range, and for causing one kind or the other of such valve movement to be of greater amount according to whether the engine temperature drops or rises, to open or close the valve respectively, the period of movement of the valve having a predetermined relationship to the said temperature range; and means for altering the said relationship to select a new temperature range for the engine.

12. Apparatus for maintaining the temperature of an engine within a desired range, comprising a fuel control valve; means for rapidly moving the fuel valve by minute equal amounts in opening and closing direction while the engine is at the desired temperature range, and for causing one kind or the other of such valve movement to be of greater amount according to whether the engine temperature drops or rises, to open or close the valve respectively, the period of movement of the valve having a predetermined relationship to the said temperature range; and means for automatically temporarily altering the said relationship in response to sudden decreases or increases in speed of the engine, to respectively open or close the said fuel valve.

13. Apparatus for maintaining the tempera-

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ture of an engine within a desired range, comprising a fuel control valve; a movable member; means for moving the member back and forth between retracted and advanced positions to have a magnitude of movement proportionate with the temperature of the engine; means for operating said fuel valve in one direction or the other according to whether the magnitude of movement of the member is greater or less than a predetermined value corresponding to the said temperature range of the engine, the magnitude of movement of the member having a predetermined relationship to the said temperature range; and means for altering the said relationship to select a new temperature range for the engine.

14. Apparatus for maintaining the temperature of an engine within a desired range, comprising a fuel control valve; a closed electrical circuit; means for introducing a uni-directional E. M. F. in the circuit, having a magnitude proportionate with the temperature of the engine to cause a current to flow in said circuit; means for periodically decreasing and restoring to its original value the said current, so as to produce oscillations having a period proportionate with the temperature of the engine; and means for oscillating said fuel valve to shift the center point of its movement in one direction or the other according to whether the period of said oscillations is greater or less than a predetermined value corresponding to the said predetermined range of the variable.

15. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising an oscillatory actuator device having means for oscillating said control device to shift the center point of its movement in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value, said oscillatory actuator device including a sensitive instrument movement, and said oscillatory actuator device being so arranged that failure of the sensitive instrument movement to function results in operation of the control device to cause the variable to attain a dangerous extreme value; and safety means, connected with the oscillatory actuator device and rendered operative upon the variable approaching said extreme value, for causing operation of the control device in one direction only whereby the variable is prevented from attaining said value.

16. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising an oscillatory actuator device having means for operating said control device in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value corresponding to said predetermined range of the variable, said oscillatory actuator device including a sensitive electric-instrument movement; and means for causing the period of oscillation of said oscillatory actuator device to be proportionate with the value of the variable, said means including a pyrometer component acted on by said variable and connected to said instrument movement, said oscillatory actuator device including contact means actuated concurrently with said control device and connected with said resistor.

17. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising an oscillatory actuator device having a deflectable member and having

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means for oscillating said control device to shift the center point of its movement in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value; and means controlling said deflectable member for causing the period of oscillation of said oscillatory actuator device to be proportionate with the value of the variable, said period of predetermined value corresponding to said predetermined range of the variable, and said oscillatory actuator device including: a pair of screen grid vacuum tubes and circuits therefor, one of said tubes having its electrodes polarized to render it normally conducting; and means, controlled by said deflectable member, for polarizing the electrodes of the other tube to render it either conducting or non-conducting, said tubes being so interconnected that said one tube is rendered non-conducting whenever the said other tube is conducting.

18. An automatic control device for use with a power-producing instrumentality which has a rotary drive shaft connected with a variable load, and which is regulated by a reversible control device governing an input of convertible energy-supplying substance to said instrumentality, comprising an oscillatory actuator device having means for operating said control device in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value; means connected to the oscillatory actuator device and responsive to and proportionately with converted energy of the input to the instrumentality for causing the period of oscillation of the oscillatory device to be proportionate with the said converted energy, said period and energy having a predetermined relationship; and means for automatically changing the relationship between said period of oscillation and converted energy in response to acceleration of said drive shaft, thereby to reduce the input of convertible energy-supplying substance to the instrumentality, said predetermined relationship being automatically reestablished upon cessation of said acceleration.

19. An automatic control device for use with a power-producing instrumentality which has a rotary drive shaft connected with a variable load, and which is regulated by a reversible control device governing an input of convertible energy-supplying substance to said instrumentality, comprising an oscillatory actuator device having means for operating said control device in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value; means connected to the oscillatory actuator device and responsive to and proportionately with converted energy of the input to the instrumentality for causing the period of oscillation of the oscillatory device to be proportionate with the said converted energy, said period and energy having a predetermined relationship; and means for automatically changing the relationship between said period of oscillation and converted energy in response to deceleration of said drive shaft, thereby to reduce the input of convertible energy-supplying substance to the instrumentality, said predetermined relationship being automatically reestablished upon cessation of said deceleration.

20. An automatic settable control device for use with a power-producing instrumentality which

has a rotary drive shaft connected with a variable load, and which is regulated by a reversible control device governing an input of fuel to said instrumentality, comprising an oscillatory actuator device having means for oscillating said control device to shift the center point of its movement in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value; means connected to the oscillatory actuator device and responsive to and proportionately with heat from fuel burned in the instrumentality for causing the period of oscillation of the oscillatory device to be proportionate with the said heat, said period and heat having a predetermined relationship; settable means for changing the predetermined relationship between said period of oscillation and heat to other predetermined relationships, thereby to change the input of fuel to the instrumentality; and means for automatically changing a predetermined relationship between said period of oscillation and heat to another relationship in response to acceleration of said drive shaft, thereby to reduce the input of fuel to the instrumentality, said predetermined relationship being automatically reestablished upon cessation of said acceleration.

21. An automatic control device for use with a power-producing instrumentality which has a rotary drive shaft connected with a variable load, and which is regulated by a reversible control device governing an input of fuel to said instrumentality comprising an oscillatory actuator device having means for oscillating said control device to shift the center point of its movement in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value; means connected to the oscillatory actuator device responsive to and proportionately with heat from fuel burned in the instrumentality for causing the period of oscillation of the oscillatory device to be proportionate with the said heat, said period and heat having a predetermined relationship; and means for automatically changing the relationship between said period of oscillation and heat in response to acceleration or deceleration of said drive shaft, thereby to reduce or increase respectively the input of fuel to the instrumentality, said predetermined relationship being automatically reestablished upon cessation of said acceleration or deceleration.

22. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument; means for energizing the electro-receptive instrument in response to said variable and proportionately with the value thereof; a mechanism for operating said powered means in one direction or the other in response to said instrument being energized respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said mechanism and powered means continually hunting; and an anticipator device for decreasing the period of hunting of said mechanism and powered means.

23. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument; means for energizing the electro-receptive instrument in response to

said variable and proportionately with the value thereof; a mechanism for operating said powered means in one direction or the other in response to said instrument being energized respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said mechanism and powered means continually hunting; and an anticipator device for decreasing the period of hunting of said mechanism and powered means, said mechanism including: a pair of screen grid vacuum tubes and circuits therefor, one of said tubes having its electrodes polarized to render it normally conducting; and means controlled by the electro-receptive instrument for polarizing the electrodes of the other tube to render it either conducting or non-conducting, said tubes being so interconnected that said one tube is rendered non-conducting whenever the said other tube is conducting.

24. An automatic control device for use with a power-producing instrumentality which has a rotary drive shaft connected with a variable load, and which is regulated by a reversible control device governing an input of convertible energy-supplying substance to said instrumentality, comprising an oscillatory actuator device having means for operating said control device in one direction or the other according to whether the period of oscillation of the oscillatory actuator device is greater or less than a predetermined value; means connected to the oscillatory actuator device responsive to and proportionately with converted energy of the input to the instrumentality for causing the period of oscillation of the oscillatory device to be proportionate with the said converted energy, said period and energy having a predetermined relationship; and means for automatically changing the relationship between said period of oscillation and converted energy in response to acceleration or deceleration of said drive shaft, thereby to reduce or increase respectively the input of convertible energy-supplying substance to the instrumentality, said predetermined relationship being automatically reestablished upon cessation of said acceleration or deceleration and said means including a pair of circuits, a D. C. electric generator driven from said drive shaft and connected to energize one of said circuits, and including a condenser charged by said generator and dischargeable through the other of said circuits.

25. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument; means for energizing the electro-receptive instrument in response to said variable and proportionately with the value thereof; and a mechanism including contact means actuated by the electro-receptive instrument and including relays controlled by said contact means, for operating said powered means in one direction or the other in response to said instrument being energized respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said mechanism and powered means continually hunting; and an anticipator device for decreasing the period of hunting of said mechanism and powered means.

26. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; a de-

flectable member; means for oscillating the deflectable member in response to said variable and proportionately with the value thereof; a mechanism for oscillating said powered means to shift the center point of its movement in one direction or the other in response to the center of movement of the deflectable member being positioned respectively in or out of a predetermined position which corresponds to said predetermined range of the variable, said mechanism and powered means continually hunting; and an anticipator device for decreasing the period of hunting of said mechanism and powered means.

27. Settable means for maintaining within any one of a plurality of predetermined ranges a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electric instrument capable of oscillation; means for energizing the electric instrument with a fluctuating current in response to said variable and proportionately with the value thereof, to cause oscillation of the instrument in step with the fluctuations of the current, the period of oscillation of said instrument and fluctuation of said current having a predetermined relationship to the value of the variable; a mechanism for oscillating said powered means to shift the center point of its movement in one direction or the other in response to said period of oscillation being respectively less than or more than a predetermined value; and manually operable means for altering the relationship between the period of oscillation of said instrument and the value of the variable, thereby to change the range in which the variable is to be maintained.

28. Settable means for maintaining with any one of a plurality of predetermined ranges a variable regulated by a reversible control device, comprising a reversible powered means for operating said control device; an electro-receptive instrument; means for energizing the electro-receptive instrument in response to said variable and proportionately with the value thereof; an anticipator device for causing oscillation of said instrument, the period of said oscillation having a predetermined relationship to the value of the variable; a mechanism for operating said powered means in one direction or the other in response to said period of oscillation being respectively less than or more than a predetermined value, said mechanism and powered means continually hunting; and manually operable means for altering the relationship between said period of oscillation and value of the variable, thereby to change the range in which the variable is to be maintained.

29. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument having a deflectable member; means for energizing the electro-receptive instrument to deflect the member thereof in response to said variable and proportionately with the value thereof, said deflectable member having a predetermined relationship to the value of the variable throughout part of the range of the variable; a mechanism for operating said powered means in one direction or the other in response to said member being deflected respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said powered means and deflectable member normally hunting; and means responsive

to movement of said powered means in one direction for automatically producing a different predetermined relationship between the member and value of the variable, reverse movement of the powered means automatically restoring the first-mentioned predetermined relationship whereby the period of hunting of the powered means and member is decreased.

30. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument having a deflectable member; means for energizing the electro-receptive instrument to deflect the member thereof in response to said variable and proportionately with the value thereof, said deflectable member having a predetermined relationship to the value of the variable throughout part of the range of the variable; a mechanism for operating said powered means in one direction or the other in response to said member being deflected respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said powered means and deflectable member normally hunting; and means responsive to movement of said powered means in one direction for automatically producing a different predetermined relationship between the member and value of the variable, reverse movement of the powered means automatically restoring the first-mentioned predetermined relationship whereby the period of hunting of the powered means and member is decreased, the said mechanism for operating the powered means including: a pair of screen grid vacuum tubes and circuits therefor, one of said tubes having its electrodes polarized to render it normally conducting; and means, controlled by the deflectable member, for polarizing the electrodes of the other tube to render it either conducting or non-conducting, said tubes being so interconnected that said one tube is rendered non-conducting whenever the said other tube is conducting, and said interconnections including a connection between the anode circuit of the one tube and the screen grid of the other tube, and including a connection between the anode circuit of the other tube and the screen grid of the one tube.

31. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument having a deflectable member; means for energizing the electro-receptive instrument to deflect the member thereof in response to said variable and proportionately with the value thereof, said deflectable member having a predetermined relationship to the value of the variable throughout part of the range of the variable; a mechanism for operating said powered means in one direction or the other in response to said member being deflected respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said powered means and deflectable member normally hunting; and means responsive to movement of said powered means in one direction and including a friction device, a contact actuated by the friction device and a resistor connected with the electro-receptive instrument and under the control of said contact, for automatically producing a different predetermined relationship between the deflect-

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able member and value of the variable, reverse movement of the powered means automatically restoring the first-mentioned predetermined relationship whereby the period of hunting of the powered means and member is decreased.

32. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electric instrument having a deflectable member; means for energizing said instrument to deflect the member thereof in response to said variable and proportionately with the value thereof, said deflectable member having a predetermined relationship to the value of said variable throughout part of the range of the variable; a selectively operable mechanism for oscillating said powered means to shift the center point of its movement in one direction or the other in response to said member being deflected respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said powered means and deflectable member normally hunting; means, connected with said mechanism for automatically producing a different predetermined relationship between the member and value of the variable when the selected operation of the mechanism is changed to reverse the powered means, resumption of original operation of the said mechanism acting to restore the first-mentioned predetermined relationship; and means responsive to movement of said powered means in one direction for automatically producing a second different predetermined relationship between the deflectable member and value of the variable, reverse movement of the powered means acting to restore the first-mentioned relationship, said means for automatically producing different predetermined relationships decreasing the period of hunting of the powered means and member.

33. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument having a deflectable member; means for energizing the electro-receptive instrument to deflect the member thereof in response to said variable and proportionately with the value thereof, said member having a predetermined relationship to the value of said variable throughout part of the range of the variable; means for operating said powered means in one direction or the other in response to said member being deflected respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable, said powered means and member continually hunting; means responsive to movement of said powered means in one direction for automatically producing a different predetermined relationship between the deflectable member and value of the variable, reverse movement of the powered means automatically restoring the first-mentioned predetermined relationship whereby the period of hunting of the powered means and member is decreased; and means responsive to said powered means attaining a predetermined limiting position for automatically rendering said powered means inoperative for movement beyond said position.

34. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an elec-

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tro-receptive instrument; means for energizing the electro-receptive instrument in response to said variable and proportionately with the value thereof; means for operating said powered means in one direction or the other in response to said instrument being energized respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable; and safety means operative upon the variable attaining a predetermined extreme value for operating the said powered means solely in one direction and independently of operation of said electro-receptive instrument.

35. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electric instrument; means for energizing said instrument in response to said variable and proportionately with the value thereof; means for oscillating said powered means to shift the center point of its movement in one direction or the other in response to said instrument being energized respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable; and safety means operative upon the variable attaining a predetermined extreme value for operating the said powered means solely in one direction and independently of operation of said electric instrument, said safety means comprising a second electric instrument energized from the same source as the first-mentioned instrument, and comprising a circuit control device connected with the means for operating the powered means.

36. Means for maintaining within a predetermined range a variable regulated by a reversible control device, comprising reversible powered means for operating said control device; an electro-receptive instrument; means for energizing the electro-receptive instrument in response to said variable and proportionately with the value thereof; means for operating said powered means in one direction or the other in response to said instrument being energized respectively less than or more than a predetermined extent which corresponds to said predetermined range of the variable; and safety means including a second electro-receptive instrument energized in response to said variable and proportionately with the value thereof for operating the said powered means solely in one direction and independently of operation of said first-mentioned electro-receptive instrument, said safety means being operative upon the variable attaining a predetermined extreme value.

37. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible, powered actuator device for moving the member in one direction or the other in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device continually hunting; and a mechanism responsive to a relatively small movement of said member in one direction or the other for operating the actuator device in the same sense as and prior to the operation it would normally have in responding to the change in the variable due to a greater movement of the member in said directions respectively, thereby to

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decrease the period of hunting of the member and actuator device.

38. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible powered actuator device for moving the member in one direction or the other in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device continually hunting; and a mechanism responsive to a relatively small movement of said member in one direction or the other and including a movable contact, a friction drive between the member and the contact, and including a resistor connector with said actuator device and controlled by said contact, for operating the actuator device in the same sense as and prior to the operation it would normally have in responding to the change in the variable due to a greater movement of the member in said directions respectively, thereby to decrease the period of hunting of the member and actuator device.

39. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible powered actuator device for moving the member in one direction or the other in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, said reversibly movable member and actuator device continually hunting; and a mechanism responsive to a relatively small movement of said member in one direction or the other for operating the actuator device in the same sense as the actuation it would normally have in responding to the change in the variable due to a greater movement of the member in said directions respectively, thereby to decrease the period of hunting of the member and actuator device.

40. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible powered actuator device for moving the member in one direction or the other proportionately in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device continually hunting, said actuator device including a translating device actuated by the variable, and including a relay; and means responsive to energization of said relay for automatically reversing the operation of the actuator device, deenergization of said relay automatically restoring the forward operation of the actuator device thereby to decrease the period of hunting of the member and actuator device.

41. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible powered actuator device for oscillating the member to shift the center point of its movement in one direction or the other proportionately in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device

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continually hunting, said actuator device including a translating device actuated by the variable, and including a relay; and means responsive to energization of said relay and including a contact and a resistor connected to said contact and to the translating device, for automatically reversing the operation of the actuator device, deenergization of said relay automatically restoring the forward operation of the actuator device thereby to decrease the period of hunting of the member and actuator device.

42. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible powered actuator device for moving the member in one direction or the other proportionately in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device continually hunting; and an anticipator mechanism responsive to forward operation of the actuator device for reversing the operation thereof, said anticipator mechanism responding to reverse operation of the actuator device by restoring forward operation thereof, thereby to decrease the period of hunting of the member and the actuator device.

43. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a reversible powered actuator device for moving the member in one direction or the other proportionately in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device continually hunting; and an anticipator mechanism operated by a predetermined minute amount of forward operation of the actuator device for reversing the operation thereof, said anticipator mechanism being operated by a predetermined minute amount of reverse operation of the actuator device to restore forward operation thereof, thereby to decrease the period of hunting of the member and the actuator device.

44. In an automatic control device, a reversibly movable member; means for controlling a variable in response to movement of said member; a selectively operable powered actuator device for moving the member in one direction or the other proportionately in response to an increase or decrease respectively in the value of said variable whereby the variable is maintained within a predetermined range, the response of said actuator device to the variable involving a time lag and said reversibly movable member and actuator device continually hunting; a mechanism responsive to one selected operation of the actuator device for automatically changing to another selected operation thereof, said mechanism responding to said other selected operation of the actuator device by restoring said one selected operation thereof; and a mechanism responsive to movement of said member in one direction for automatically changing to said other selected operation of the actuator device, said second-mentioned mechanism responding to movement of the member in the opposite direction by restoring said one selected operation of the actuator device, and both said mechanisms acting to

decrease the period of hunting of the member and actuator device.

45. An automatic control for use with an instrumentality heated by a heating medium, comprising a reversible control device for said medium; reversible powered means for operating said control device; a sensitive electric-instrument movement having a deflectable member; means for energizing the instrument movement with an oscillating current which is responsive to and proportionate with heating of said instrumentality, the response of the instrument movement to a change of temperature of said instrumentality involving a time lag; means for oscillating said powered means to shift the center point of its movement in one direction or the other in response to the center movement of the deflectable member occupying respectively one position or a different position, said control device and powered means continually hunting; and anticipator means increasing the speed of said hunting beyond the normal for said control device and powered means.

46. A settable automatic control for use with an instrumentality heated by a heating medium, comprising a reversible control device for said medium; reversible powered means for operating said control device; a sensitive electric-instrument movement having a deflectable member; means for energizing the instrument movement responsive to and proportionate with heating of said instrumentality, the range of movement of the deflectable member having a predetermined relationship to the temperature of said instrumentality throughout part of the range of said temperature; means for oscillating said powered means to shift the center point of its movement in one direction or the other in response to the center of movement of the deflectable member being respectively in an advanced or a retracted position, said central device and powered means continually hunting; and manually settable means for altering said relationship between the member and temperature of the instrumentality, thereby to change the conditions to be maintained by the control.

47. An automatic control device for use with an instrumentality heated by a heating medium, comprising a reversible control device for said medium; reversible powered means for operating said control device; a sensitive electric-instrument movement having a deflectable member; means for operating said powered means in one direction or the other in response to the deflectable member being respectively in an advanced or a retracted position; means for energizing the instrument movement in response to and proportionately with heating of said instrumentality, the response of the instrument movement to a change of temperature of said instrumentality involving a time lag, and the deflectable member having a predetermined relationship to the temperature of said instrumentality throughout part of the range of said temperature, said deflectable member and powered means continually hunting; and means responsive to movement of said powered means in one direction for automatically producing a different predetermined relationship between the deflectable member and the temperature of the instrumentality, reverse movement of the powered means automatically restoring the first-mentioned predetermined relationship whereby the period of hunting of the deflectable member and powered means is decreased.

48. A settable automatic control device for use with an instrumentality heated by a heating medium, comprising a reversible control device for said medium; reversible powered means for operating said control device; a deflectable member; means for operating said powered means in one direction or the other in response to the deflectable member being respectively in an advanced or a retracted position; means for deflecting the deflectable member in response to and proportionately with heating of said instrumentality, the response of the member to a change of temperature of said instrumentality involving a time lag, and the member having a predetermined relationship to the temperature of said instrumentality throughout part of the range of said temperature, said deflectable member and powered means continually hunting; manually settable means for altering said relationship, thereby to change the conditions to be maintained by the control; and means responsive to movement of said powered means in one direction for automatically producing a different predetermined relationship between the deflectable member and the temperature of the instrumentality, reverse movement of the powered means automatically restoring the first-mentioned predetermined relationship whereby the period of hunting of the deflectable member and powered means is decreased.

49. A settable automatic control device for use with an instrumentality heated by combustion of fuel, comprising fuel flow-control means; reversible powered means for operating said flow-control means to increase or decrease the fuel flow; a deflectable member; means for oscillating the deflectable member in response to and proportionately with heating of said instrumentality, the center of movement of the member having a predetermined relationship to the temperature of said instrumentality throughout a part of the range of said temperature; manually settable means for altering said relationship, thereby to change the conditions to be maintained by the control device and means for oscillating said powered means to shift the center point of its movement in one direction or the other in response to the center of movement of the deflectable member being positioned in or out of a predetermined position respectively.

50. An automatic control device for use with an instrumentality heated by combustion of fuel, comprising fuel flow-control means; reversible powered means for operating said flow-control means to increase or decrease the fuel flow; a deflectable member; means for operating said powered means in one direction or the other in response to the deflectable member being positioned in or out of a predetermined position respectively; means for deflecting the deflectable member in response to and proportionately with heating of said instrumentality, the member having a predetermined relationship to the temperature of said instrumentality throughout a part of the range of said temperature, the response of the member to a change of temperature of said instrumentality involving a time lag, and said deflectable member and powered means continually hunting; and means responsive to movement of said powered means in one direction for automatically producing a different predetermined relationship between the member and the temperature of the instrumentality, reverse movement of the powered means automatically restoring the first-mentioned predetermined re-

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lationship whereby the period of hunting of the deflectable member and powered means is decreased.

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