

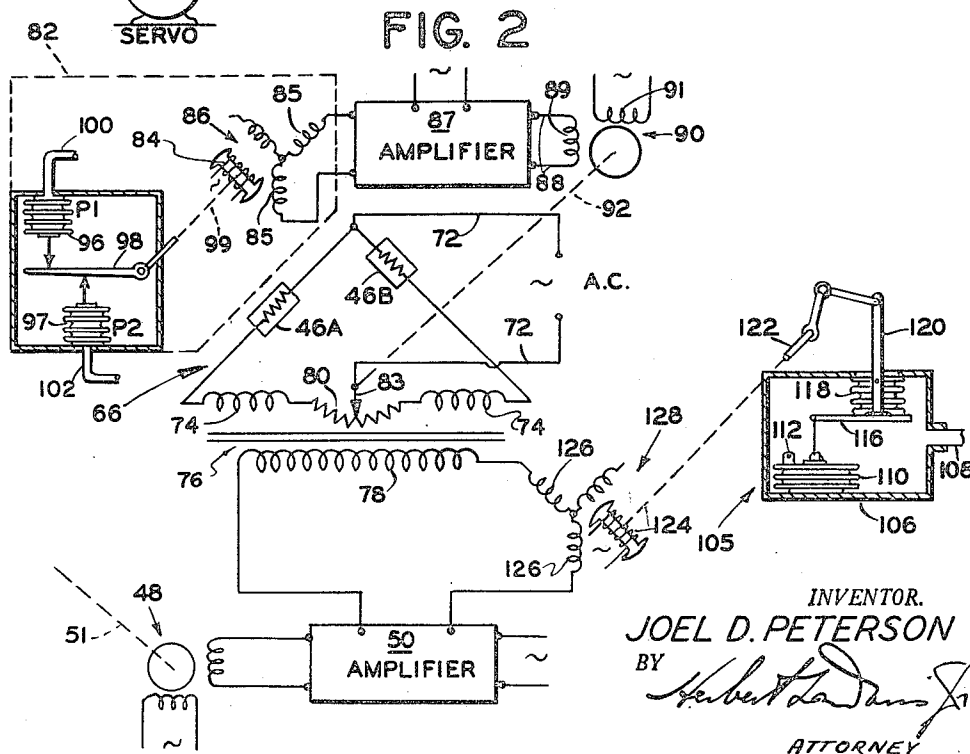
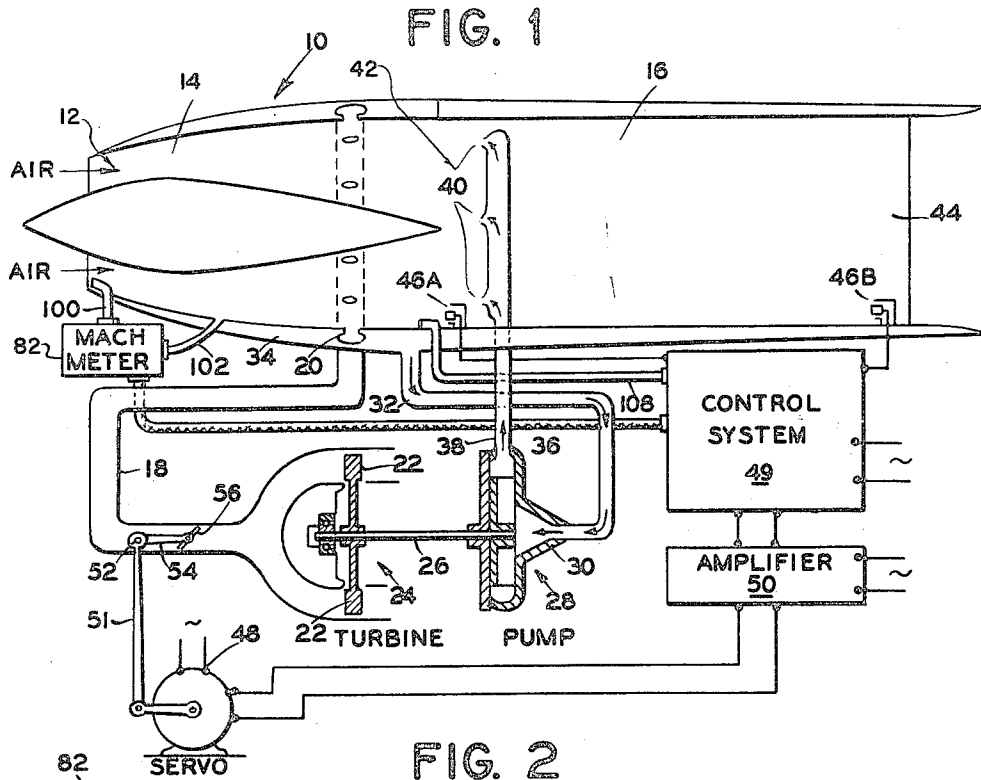
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AIR-FUEL RATIO CONTROL SYSTEM FOR RAM-JET ENGINES

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AIR-FUEL RATIO CONTROL SYSTEM FOR
RAM-JET ENGINES

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6 Claims. (Cl. 60—39.28)

The present application relates to improvements in an air-fuel ratio control system for ram jet engines of the type disclosed and claimed in the copending application Serial No. 142,808, filed February 7, 1950, by Walter D. Teague, Jr. and Pasquale A. De Padova and assigned to Bendix Aviation Corporation, now Patent No. 2,736,167.

A ram jet engine cannot start operating by itself. A missile powered by a ram jet engine needs to be launched from a suitable apparatus or other aircraft, and once the ram jet is started, it will sustain itself in flight by generating its own power. A power plant of this character is designed for operation at a predetermined altitude, and it is, therefore, desirable to maintain the air-fuel ratio most advantageous for that altitude substantially constant.

A ram jet of the type contemplated to control herein generally involves at least one combustion chamber, a centrifugal pump, a bank of injectors, and a turbine all housed within a streamlined tubular casing. Air enters the casing at an inlet of a suitable flow passage and is compressed by a diffuser type pressure recovery. A small portion of the compressed air then passes on to drive a turbine which in turn drives a centrifugal fuel pump which pumps fuel into the combustion chamber. The main flow of the compressed air is then mixed with the fuel atomized by the nozzles of the fuel injector. The air and fuel mixture is then ignited by some suitable means and burns steadily thereafter. The hot gases or modified fluid comprises the products of combustion and are then directed generally into the tail pipe and then discharged at high velocity to the atmosphere so that the energy therefrom is used to propel the craft.

An object of the invention is to provide a novel combustion chamber pressure rate sensing unit for stabilizing a system for controlling the air fuel ratio of such a ram jet engine.

Another object of the invention is to provide novel means for varying the temperature setting of the control system with change in Mach number so as to maintain the Mach number substantially constant.

The above and other objects and features of the invention will appear more fully hereinafter from a consideration of the following description taken in connection with the accompanying drawing wherein one embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purposes of illustration only and is not to be construed as defining the limits of the invention.

Referring to the drawing wherein like reference characters designate like parts,

Figure 1 is a schematic drawing of a ram jet engine showing the various components of the air fuel ratio regulating system attached thereto.

Figure 2 is a wiring diagram of one embodiment of the regulatory means of the invention.

Referring now to the drawing, a ram jet engine generally designated by the numeral 10 comprises an inlet 12 leading past the venturi section 14 into a combustion

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chamber 16. A duct 18, by means of an aperture 20, leads a portion of the incoming air to the buckets 22 of a turbine 24. A shaft 26 connects the turbine to the driving shaft of a centrifugal pump 28. The inlet 30 of the pump 28 connects to line 32 which leads to a fuel reservoir 34 and the outlet 36 of the pump 26 connects to line 38 which leads to the fuel injectors 40 in the combustion chamber 16.

Protruding within the combustion chamber 16 at the inlet 42 and at the outlet 44 thereof are temperature probes 46A and 46B, respectively, adapted to measure the temperature of high velocity and high temperature gases. The high temperature probes 46A and 46B are of the type more specifically disclosed in copending application Serial No. 63,381, filed December 3, 1948, on Temperature Probe, in the name of William R. Polye, and assigned to Bendix Aviation Corporation, the assignee of the present application, now Patent No. 2,579,271.

The temperature probe 46A is disposed so as to measure the inlet 42 temperature, while the temperature probe 46B measures the outlet 44 temperature of the combustion chamber 16. The probes 46A and 46B are connected through a suitable regulating circuit 49 to an amplifier 50 of a type well known in the art, the output from which controls a motor 48. The electric motor 48 is of a type commonly known in the art, such as a two-phase motor, adapted to exert either a pushing or pulling force upon a rod 51 which is in turn attached as at 52 to a lever 54 which operates a butterfly type valve 56 in the duct 18. The butterfly valve 56 controls the flow of air through the duct 18 to the turbine 24 and consequently the speed thereof.

Referring now to Figure 2 wherein one embodiment of a number of regulating circuits which will readily occur to those skilled in the art is illustrated by way of example, the temperature probes 46A and 46B are placed in opposite arms of a bridge circuit 66, having conductors 72 leading from a main source of constant frequency alternating current across the bridge. Primary 74 of a transformer 76 forms part of the bridge circuit. The secondary 78 of the transformer 76 is connected to the amplifier 50 which in turn feeds power of a phase determined by the balance of the bridge circuit to the motor 48 to cause the motor to rotate in a direction to regulate the butterfly valve 56 and thereby the speed of the turbine 24. A balancing potentiometer 80 including adjustable arm 83 serves to initially balance the bridge 66 at a predetermined differential between inlet and outlet temperature as sensed by the probes 46A and 46B, the resistance of which increases with increase in temperature and conversely decreases with decrease in temperature. The bridge thereafter will be balanced and unbalanced by the differential of the resistance across the probes 46A and 46B at the inlet and outlet of the combustion chamber 16.

Mach number control

A novel feature of the present invention is the provision of a Mach number regulator 82 to control the adjustment of the movable arm 83 of the balancing potentiometer 80 through a suitable servo mechanism so as to vary the temperature setting of the bridge to maintain a constant Mach number. The servo mechanism includes a rotor winding 84 connected across the main source of alternating current and inductively coupled to stator windings 85 of a variable coupling transformer 86. The variable coupling transformer 86 is of a conventional type having a pair of stator windings 85 reversely wound and arranged so that rotor winding 84 when adjusted to a predetermined balance point bisects the angle made by the juncture of the two active stator windings 85 so as

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to effect a zero signal; while adjustment of the rotor winding 84 to one side of the balance point effects a signal voltage of one phase and adjustment to the other side of the balance point a signal voltage of the opposite phase. Conductors lead from the stator winding 85 to the input of an amplifier 87 which may be of conventional type. Output conductors 88 lead from amplifier 87 to a control winding 89 of a two-phase servomotor 90 also of conventional type and having a fixed phase winding 91 connected across the main source of alternating current. The motor 90 is reversible and controls through a shaft 92 the adjustment of arm 83 of the potentiometer 80 in a direction dependent upon whether the controlling signal voltage is of one phase or the opposite phase.

The regulator 82 includes bellows 96 and 97 acting differentially on an arm 98 to actuate a shaft 99 to adjustably position the winding 84 of the variable coupling transformer 86 so as to control motor 90 and thereby potentiometer 80 to increase or decrease the temperature of the combustion gases in the chamber 44.

The interior of the bellows 96 is subject to ram air inlet pressure P-1 applied through a tube 100 opening at the inlet 12 to the venturi section 14 while the interior of the bellows 97 is subject to the pressure P-2 at the throat of the venturi section 14 applied through a tube 102.

In order to maintain a constant Mach number and air flow through the venturi section 14, a decrease in the pressure P-1 affecting bellows 96 or increase in the pressure P-2 affecting bellows 97 causes the bellows 96 to collapse and bellows 97 to expand causing in turn an adjustment of arm 98 in a clockwise direction. This adjustment of arm 98 effects through the variable coupling transformer 86 and amplifier 87 a signal voltage to the motor 90 of a phase such as to cause rotation of arm 83 in a counterclockwise direction so as to increase the temperature setting of the probe 46B which in turn unbalances the bridge 66 requiring more fuel to be applied to the combustion chamber 16 to balance the bridge 66. Such increase in fuel causes the flow of air through the venturi section 14 to increase so as to in turn decrease the pressure P-2 in the bellows 97 so as to balance the pressure P-1 in the bellows 96. Of course, upon the pressure P-1 in the bellows 96 increasing or the pressure P-2 in the bellows 97 decreasing, the temperature setting of the probe 46 B is decreased by a resulting adjustment of the arm 83 in a clockwise direction by the servomotor 90. Thus by varying the temperature setting, a substantially constant Mach number and air flow through the venturi section 14 may be maintained. When the arm 98 is at a predetermined balanced position at which the Mach number is at the desired value, the rotor winding 84 is adjusted by the differential bellows 96 and 97 to a neutral position at which there is a zero signal to the amplifier 87 causing the motor 90 to remain in the adjusted position. Unbalancing of this relationship causes a signal voltage to be applied to the servomotor 90 of such a phase as to cause rotation in a direction depending upon the direction of unbalance as heretofore indicated.

A further feature of the present invention is the provision of a pressure rate sensing unit for providing stability of control to the system.

The rate of change of air pressure immediately before the air enters the combustion chamber 16 is sensed by a rate sensing unit 105 including a sealed chamber 106 connected through a tube 103 opening at a point immediately before the combustion chamber 16. Mounted within the chamber 106 is a bellows 110, the interior of which is connected through a capillary leak 112 with the interior of the chamber 106 so as to allow the bellows 100 to stay at zero deflection regardless of any constant pressure applied at the exterior surface, while the bellows 110 deflects in proportion to the rate of change of pressure applied in the chamber 106.

The bellows 110 is connected through a suitable me-

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chanical linkage including arm 116, sealing bellows 118, and pivoted arm 120 linked to a shaft 122 for positioning a rotor winding 124 inductively coupled to stator windings 126 of a variable coupling transformer 128. The variable coupling transformer 128 is of a conventional type having a pair of stator windings 126 reversely wound and arranged so that rotor winding 124 when adjusted to a predetermined balance point bisects the angle made by the juncture of the two active stator windings 126 so as to effect a zero signal; while adjustment of the rotor winding 124 to one side of the balance point effects a signal voltage of one phase and adjustment to the other side of the balance point a signal voltage of the opposite phase. The stator windings 126 are connected in series between the secondary winding 78 of the transformer 76 and the amplifier 50 controlling the motor 48. The winding 124 is connected to the main source of alternating current and is arranged to induce a zero signal voltage in the stator winding 126 while constant pressure is applied to the interior of the bellows 110. However, upon an increase in the pressure applied through the tube 108 as upon an increase in fuel, the bellows 110 collapses adjusting the rotor winding 124 in a direction for inducing in the stator windings 126 a signal voltage of such a phase as to call for rotation of the motor 48 in a direction to decrease the fuel supplied to the combustion chamber 16 so as to tend to retard rotation of the motor 48 in a direction calling for increase in fuel.

Likewise, upon a decrease in the pressure applied through the tube as upon a decrease in fuel, the bellows 110 expands adjusting the rotor winding 124 in a direction for inducing in the stator windings 126 a signal voltage of such a phase as to call for rotation of the motor 48 in a direction to increase the fuel supplied to the combustion chamber 16 and tending to retard rotation of the motor 48 in a direction calling for decrease in fuel and thereby providing an anticipatory effect which provides stability of control to the system. Of course, such anticipatory effect is present only during periods of pressure change and the retarding effect is wiped out as soon as a constant pressure is applied to the chamber 106, since the capillary air leak 112 tends to balance the pressures acting interiorly and exteriorly of the bellows 110.

Operation

It will be seen from the foregoing that the subject application relates to a novel system for maintaining a substantially constant flight Mach number with controlled fuel-air ratio in a ram jet engine or other similar device and involves improvements in the control system disclosed and claimed in the copending application Serial No. 142,808, filed February 7, 1950, by Walter D. Teague, Jr. and Pasquale A. De Padova.

The fuel-air ratio control is based on the principle that:

$$\frac{A}{F} = \frac{ah}{C_{pc}} \left(\frac{1}{T_{s4} - T_{s3}} \right) - 1$$

where

60 $\frac{A}{F}$ = air fuel ratio

a = lower heating value of fuel

h = combustion chamber efficiency

65 C_{pc} = average specific heat at constant pressure in the combustion chamber

T_{s4} = combustion chamber stagnation outlet temperature

T_{s3} = combustion chamber stagnation inlet temperature

70 For a given combustion chamber and a unit flying at constant Mach number in the isothermal zone, all values except T_{s4} and

$\frac{A}{F}$

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are constant. Hence a measurement of T_{s4} measure

$$\frac{A}{F}$$

As indicated on the accompanying drawings, the magnitude of T_{s4} is measured by suitable means and the output signal fed into an amplifier.

The system also incorporates a Mach error indicator which is based on the principle that

$$P_p = P_o \left(1 + \frac{a-1}{2} M_o^2 \right) \frac{a}{a-1}$$

where

P_p = stagnation pressure

P_o = static pressure

a = ratio of specific heats

M_o = flight Mach number

and for a constant flight Mach number the ratio of P_p/P_o is constant. Thus the ratio of stagnation pressure to static pressure is sensed and a signal proportional to the deviation from a desired flight Mach number is fed into the amplifier.

Since the thrust of a combustion chamber is based on:

$$C_F = f \left(\frac{S_5}{S_3}, M_o, T_o, \frac{A}{F} \right)$$

where

C_F = thrust coefficient

S_5/S_3 = ratio of areas

M_o = flight Mach number

T_o = ambient temperature

A/F = air to fuel ratio

and for a given unit the ratio of areas is constant and since the unit will operate in essentially the isothermal zone, C_F is a function of M_o and A/F .

Hence the A/F is varied to give the proper thrust to obtain the given Mach number. The measurement of T_{s4} and M_o are integrated in the control system and the output is put into a servo driven throttle control of a turbo-pump, the positioning of which determines the proper fuel flow to give the desired A/F ratio.

In order that the system be stable in operation, a rate sensing device is incorporated. The device measures the rate of change in the pressure of the air to the combustion chamber and its signal is combined in the control system to temper the output from the measurement of T_{s4} and Mach number deviation.

Although only one embodiment of the invention has been illustrated and described, various changes in the form and relative arrangements of the parts may be made to suit requirements.

What is claimed is:

1. For use in controlling the air fuel ratio in a ram jet engine having a combustion chamber with an air inlet and means for supplying fuel to the combustion chamber; the combination comprising combustion gas temperature responsive means, means for regulating the fuel supply means, means operatively connecting said temperature responsive means to the fuel supply regulating means, said fuel supply regulating means being controlled by said temperature responsive means so as to maintain said

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combustion gas at a selected temperature, means for changing the datum of said regulating means to vary the selected temperature, and combustion chamber inlet air flow pressure responsive means to operate said datum changing means so as to effect a predetermined air flow condition.

2. The combination defined by claim 1 in which said fuel supply regulating means includes a bridge circuit controlled by said temperature responsive means, a variable resistance element for changing the datum of said bridge circuit, and a reversible motor means controlled by the air flow pressure responsive means to operate the variable resistance element.

3. The combination defined by claim 2 in which said air flow pressure responsive means includes a pair of differentially operated membranes for sensing the air flow to the combustion chamber, and inductive coupling means operated by said membranes for controlling said motor means.

4. For use in controlling the air fuel ratio in a ram jet engine having a combustion chamber with an air inlet and means for supplying fuel to the combustion chamber; the combination comprising combustion gas temperature responsive means, means for regulating the fuel supply means, means operatively connecting said temperature responsive means to the fuel supply regulating means, said fuel supply regulating means being controlled by said temperature responsive means so as to maintain said combustion gas at a selected temperature, and an air inlet pressure sensitive device for retarding the effect of said temperature responsive means on said regulating means upon changes in said air inlet pressure.

5. For use in controlling the air fuel ratio in a ram jet engine having a combustion chamber with an air inlet and means for supplying fuel to the combustion chamber; the combination comprising combustion gas temperature responsive means, means for regulating the fuel supply means, means operatively connecting said temperature responsive means to the fuel supply regulating means, said fuel supply regulating means being controlled by said temperature responsive means so as to maintain said combustion gas at a selected temperature, and a membrane responsive to the rate of change in the air inlet pressure to the combustion chamber for retarding the effect of said temperature responsive means on said regulating means to provide stability of control.

6. The combination defined by claim 5 in which said fuel supply regulating means includes a bridge circuit controlled by said temperature responsive means, and inductive coupling means operated by said membrane for applying a voltage for retarding the effect of said bridge circuit on said regulating means.

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