Oct. 18, 1955 J. M. MERGEN ET AL 2,720,927

PROPELLER CONTROL SYSTEM

Filed Sept. 21, 1951 2 Sheets-Sheet 1

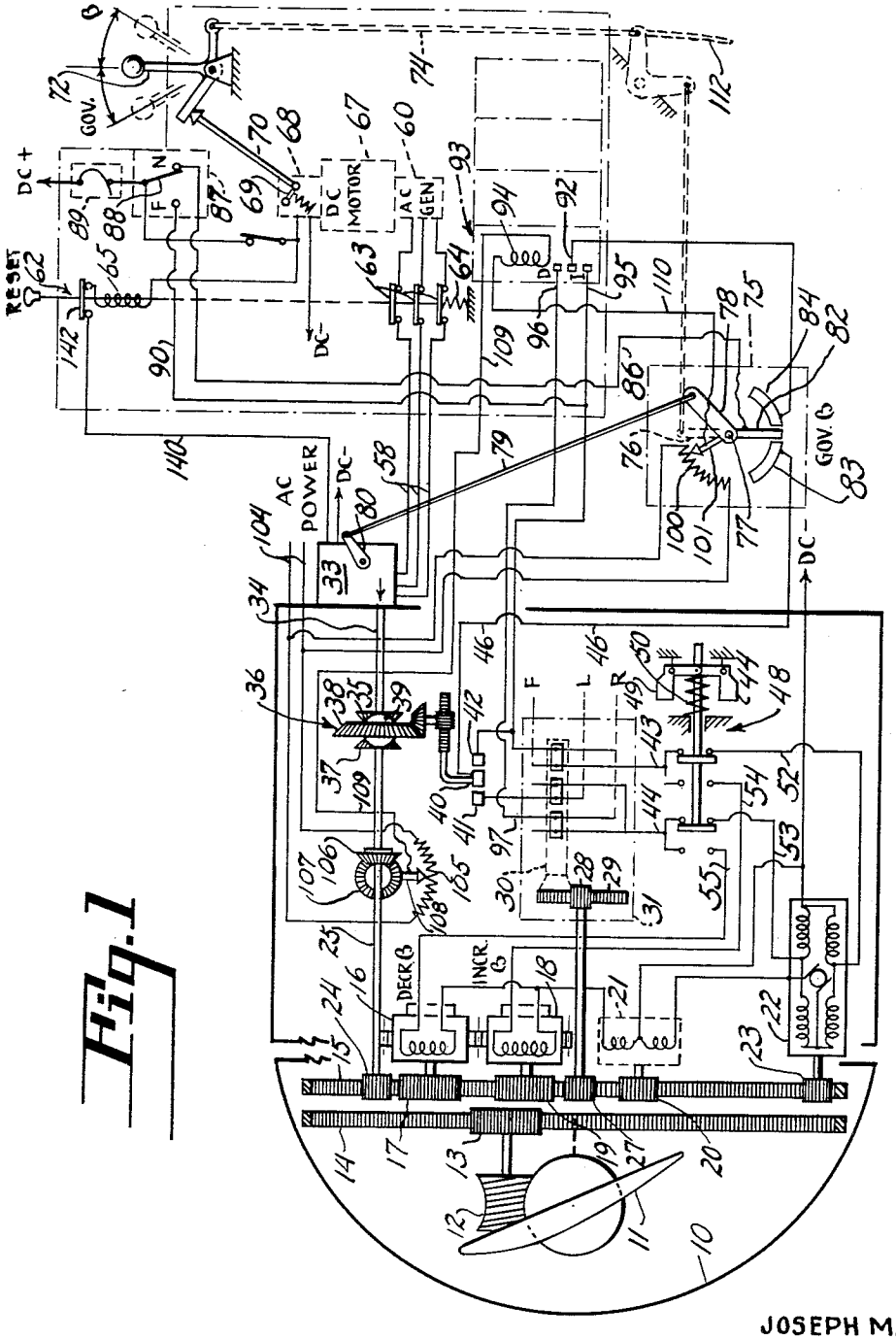


Fig. 1

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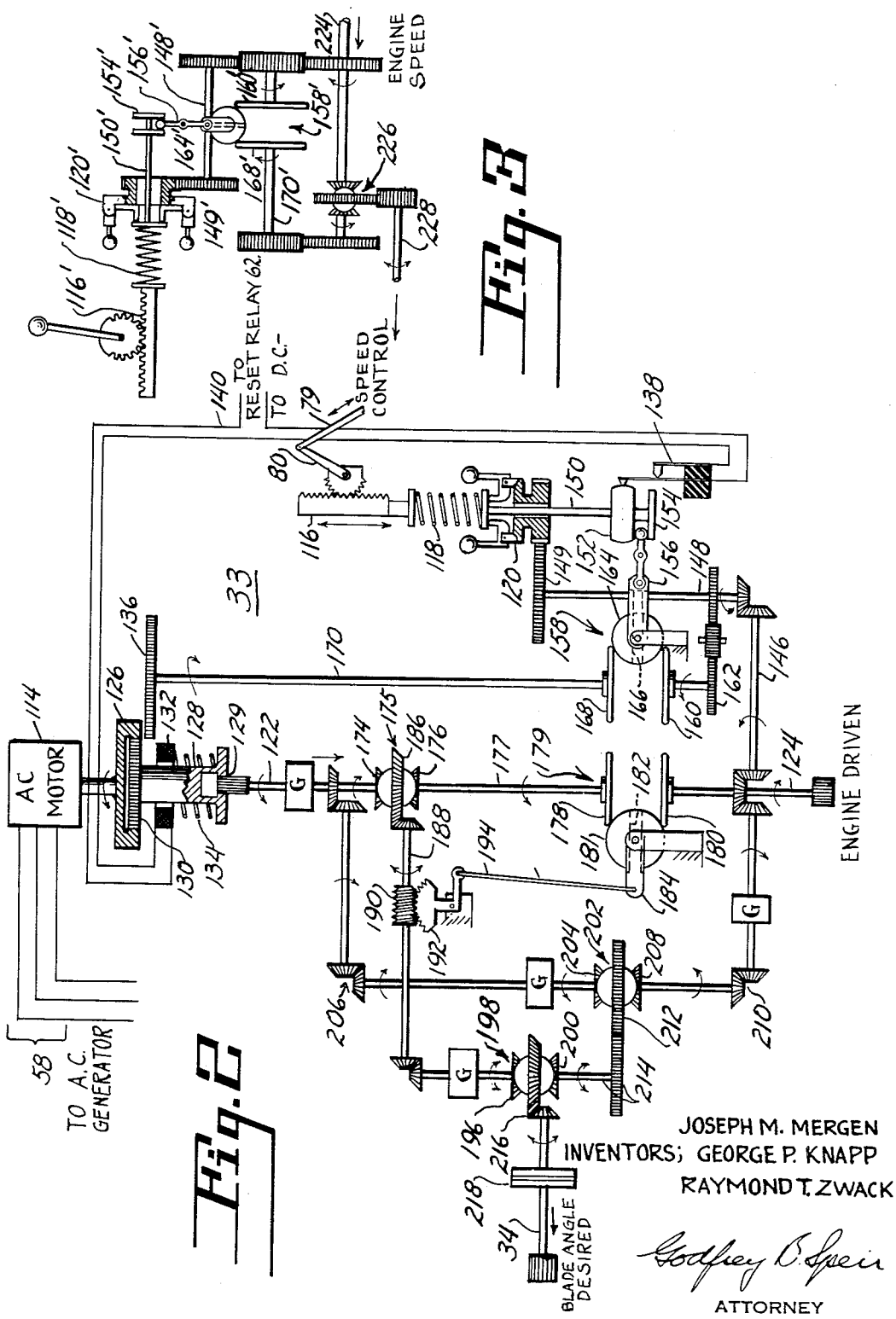


Fig. 3

Fig. 2

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PROPELLER CONTROL SYSTEM

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Application September 21, 1951, Serial No. 247,668

14 Claims. (Cl. 170—160.18)

This invention relates to control systems and apparatus adapted particularly for the control of variable pitch aircraft propellers driven by internal combustion turbines. The control system herein is based upon the idea of jointly controlling turbine power and turbine R. P. M. by a single control lever or equivalent instrumentality, the single control lever being movable in a plurality of positions, each lever position operating upon the propeller and the turbine to produce a particular relationship of turbine power and turbine R. P. M.

This principle has been applied in the past to reciprocating aircraft engines and propeller combinations wherein power and R. P. M. are scheduled by a uni-lever control. In the case of reciprocating engine-propeller combinations, the uni-lever control system is somewhat more simple than for turbine-propeller power plants. The control of the turbine-propeller power plant, hereinafter called turboprop, must be more precise in regulating fuel feed or propeller pitch to hold turbine speed, turbine temperatures and other operating characteristics within safe limits and in stable relation.

In the present system, variations in propeller pitch are intended primarily to control turbine R. P. M. while variations in fuel feed to the turbine effect, primarily, engine power, torque, turbine blade temperature and related factors.

In co-pending application Serial No. 694,398, filed August 31, 1946, now U. S. Patent No. 2,631,677, in the names of Kochenburger et al., a rather complete background is recited which presents the fundamental control problems in a turboprop installation. That application approaches the problem, after the initial analysis is given, on the basis that propeller blade angle is utilized to control engine power or torque while fuel feed to the turbine is utilized to control turbine speed. This approach to the problem, opposite to the one herein contemplated, is also developed in further improvements in Knapp et al. applications Serial Nos. 165,548, filed June 1, 1950, and 40,476, filed July 24, 1948, now U. S. Patent No. 2,640,550.

The present application comprises in part, further development and improvement on a fundamental type of acceleration responsive speed governing system disclosed in Robbins application Serial No. 234,888, filed July 2, 1951, now U. S. Patent 2,667,344.

The present system, as well as the systems of the above mentioned applications, are applicable to a number of different types of propeller mechanisms which are equipped for so-called beta control. That is, the propeller is so designed that a movable control element therein may be positioned to call for specific blade angles whereupon, the propeller mechanism operates to attain the particular blade angle called for by the control element. Several such propellers have been developed by assignee of the present applicants and the one which is most relevant herein is disclosed in Mergen et al. application Serial No. 143,636, filed February 11, 1950. This propeller utilizes the power of propeller rotation to effect

pitch changes, this power being clutched selectively and by electrical means, to alter propeller blade pitch, either to decrease it or to increase it. Additional beta control types of propellers which could be adapted in the present invention are disclosed in Mergen et al. application Serial No. 73,586, filed January 29, 1949, now U. S. Patent No. 2,646,131, Mergen et al. application Serial No. 34,984, filed June 24, 1948, now U. S. Patent No. 2,699,220, and Cushman et al. application Serial No. 771,022, filed August 28, 1947, now U. S. Patent No. 2,657,755. The propellers disclosed in the latter three applications are of the hydraulically controlled type, adapted to assume a particular blade angle in response to movement of a control element to a position calling for a particular blade angle.

In the present invention, a single coordinated power control lever is provided with several ranges of movement. In one range, governed turbine speed is afforded with a coordinated schedule of turbine power. In another range of control member movement, particular values of propeller blade angle are coordinated with the turbine fuel feed to the turbine to attain particular combinations in the turbine power schedule to meet conditions of reverse pitch operation, and starting of the turbine whereat propeller pitch is required to be nearly zero to minimize turbine starting torque. The governed speed range is in general the high power range of turbine operation. In the present invention, complete control mechanism is provided to attain response of the propeller either to a governed required speed or to a particular blade angle as called for by the power lever. In addition, provisions are made for certain types of emergency operation wherein the propeller is required to be feathered either selectively or as an emergency requirement in view of engine failure.

In the governor system for the propeller, which is one of the principal parts of the invention, two governor units are provided, the main one of which coordinates with a synchronizer apparatus which is adapted to serve a plurality of turboprop units. Should any failure of the normal governor system of a single propeller occur, automatic means are provided to switch the synchronizing governor control over to a governor control which is operated by the individual turbine and which will hold that turbine on-speed for the selected power and R. P. M. setting established by the position of the power lever.

The various elements and units of the invention in their coordinated relationship will be explained in connection with the attached drawings which represent a preferred embodiment of the invention. In these drawings, similar reference characters indicate similar parts and Fig. 1 is a schematic diagram of the overall control system;

Fig. 2 is a schematic diagram of the normal and standby governor system which is shown in Fig. 1 as a box; and

Fig. 3 is an alternative embodiment of an engine controlled governor unit.

Reference may first be made to Fig. 1 which shows schematically, a controllable pitch propeller, pitch changing mechanism therefor, means to control the pitch of the propeller in response to governor operation, means to set the governor, means to set the pitch of the propeller in response to a call for a desired blade angle, and means to call for a desired blade angle. This system as will become clear, cooperates with a turbine control system, not shown, by which the fuel feed to the turbine is regulated.

We show schematically a propeller hub 10, one blade of the propeller being shown at 11, the propeller blade 11 being mounted in the hub in known manner. The pitch of the blade 11 is changed by means of a worm and wheel arrangement 12, the worm being driven by a hub-carried

pinion 13 driven by a ring gear 14 rotatable with and with respect to the propeller hub. A control ring gear 15 is mounted on the hub, this gear being normally non-rotatable but being rotatable in either direction as will be seen to produce rotation of the gear 14 with respect to the hub. A gearing mechanism, not shown, connects the gears 15 and 14 to transmit pitch changing movements. Such an intergearing mechanism is known in the art and is shown in patent application Serial No. 675,383, filed June 8, 1946, now U. S. Patent No. 2,640,552. A showing of the gearing also appears in application Serial No. 143,636, filed February 11, 1950.

The propeller pitch changing mechanism includes an electrically operated clutch 16 which may be energized to decrease propeller pitch, the clutch body, driven by the propeller shaft, being clutchable to a pinion 17 engaging the gear 15. An increase pitch clutch 18, geared to the clutch 16 and rotated in opposite direction, is energizable to secure a pinion 19 for rotation therewith, the pinion 19 being meshed with the ring gear 15. In addition to the above, a pinion 20 meshed with the ring gear 15 may be electrically braked by a unit 12 to hold it from rotation and thus to hold the gear 15 from rotation. To provide for propeller pitch change should rotation of the propeller be at very low speed, a reversible electric motor 22 is provided which when energized, may drive a pinion 23 which is meshed with the gear 15, thereby to rotate the gear and to effect changes in pitch in the propeller. A pinion 24 is meshed with the gear 15 and comprises, through its shaft 25, a means to indicate existing pitch of the propeller, since the rotational position of the gear 15 comprises at all times an index of the pitch setting of the propeller blade 11. A supplementary pinion 27, meshed with the gear 15, is connected to and rotates a pinion 28 in response to the rotation of the gear 15, the pinion 28 being meshed with the rack 29 which moves a member 30 up and down, the member carrying switch bars cooperating with contacts on a panel 31 to comprise limit switches for feather, normal low pitch, reverse pitch, and any additional pitch limits which may be desired.

A dual governor unit 33 is provided as a part of the propeller which governor, shown in detail in Fig. 2, has an output shaft 34 whose rotational position is representative of the pitch angle desired in the propeller. The shaft 34 carries a bevel pinion 35 forming part of a differential unit 36, the pitch indicator shaft 25 also carrying a bevel pinion 37 opposing the gear 35. A bevel gear 38 lies between the gears 35 and 37 and carries spider pinions 39. Any rotation of the normally non-rotating gears 35 and 37 with respect to each other will rotate the ring gear 38 to an amount proportional to the difference between the pitch called for and the existing pitch of the propeller. This pitch error signal is transmitted to the center point 40 of a switch, the point 40 being engageable with switch points 41 or 42 which directs pitch increasing or pitch decreasing electrical energy fed to the point 40 through the limit switch organization 30, 31 to pitch increase or pitch decrease wires 43 and 44 respectively and thence to the appropriate pitch changing elements of the propeller. When operating on the governor, electrical power is provided to the central switch point 40 through a wire 46 in a manner which will later be described. The wires 43 and 44 are connected to a multiple point centrifugally operated switch 48. This switch is so arranged that if propeller R. P. M. drops below some predetermined value such as 200 R. P. M., the flyweights 49 move inwardly under the influence of the spring 50 to connect the wire 43 to a wire 52 and to connect the wire 44 to a wire 53. If rotation of the propeller is in excess of the predetermined value, the flyweights 49 move outwardly and shift the switch so that wire 43 is connected to a wire 54 and so that wire 44 is connected to a wire 55. If wires 52 and 53 are active, the standby electric motor 22 may be energized for either forward or reverse rotation to increase or decrease pitch in accordance with the call made therefore by the pitch control switch 40, 41, 42. If the wires 54 and 55 are active, a call for pitch change made by the pitch control 40, 41, 42 will energize either the increase pitch clutch 18 or the decrease pitch clutch 16 to cause pitch change in the propeller, the power therefore being drawn from the rotation of the propeller shaft. The circuits are so arranged that the brake 21 is energized concurrently with a call for pitch change either by the clutches or by the motor 22. This brake is normally spring loaded into braking position to hold the propeller from pitch change. When electrically energized, the brake 21 is moved against the spring to non-braking position to permit the pitch change either by action of the clutches 16 or 18 or by the action of the motor 22.

Let it be assumed for the moment that the governor 33 produces the desired blade angle signal, and that the governor functions to call for the proper blade pitch angle to produce a desired propeller and engine speed. This governor as will be described, contains a synchronous motor which is provided with power through wires 58 from a three-phase alternating current generator 60, the generator feeding the wires 58 through a reset relay 62 having switch arms 63. The reset switch is normally urged by a spring 64 to disconnect the points 63 and is held in a point engaging position by the action of a normally energized solenoid 65. The A. C. generator 60 is driven by a variable speed direct current motor 67 fed from a D. C. power supply, the speed of the motor being controlled by a controller 68 which is adjustable through a lever 69 connected, through a strut 70, to a turbine control lever 72. The lever 72 when moved from the vertical position as shown, to the left, moves the strut 70 downwardly and adjusts the motor speed regulator 68 for gradually increasing speed. At the vertical position, the lever 72 adjusts the motor speed regulator 68 to a minimum speed position. When the lever 72 is moved to the right from the vertical position, it has no further effect upon the motor speed regulator but transfers regulation of propeller pitch to a blade angle control arrangement which will be described shortly.

The lever 72 is connected by mechanical linkage 74 to a "power coordinator" unit 75 through an arm 76 rotating a lever system on an axle 77. To this axle is secured a lever 78 connected by a rod 79 to a lever 80 on the governor unit 33 which as will be seen, provides mechanical adjustment for a portion of the governor.

The axle 77 also carries a selector switch arm 82 engageable with a switch segment 83 when the power lever 72 is in the range for governing. The lever 82 connects with a switch segment 84 when the power lever 72 is in the range for blade angle control. If the lever 82 and the segment 83 are connected, an electrical power path is established from the wire 46, connected to the segment 83, to a wire 86 connected to the lever 82, and connected also to manually operable selector switch 87 and thence through a switch arm 88 to a circuit breaker 89 and to a source of D. C. power. In this fashion, when the switch 88 is adjusted for normal operation as shown, power supply is led to the pitch controlling switch 40, 41, 42 to permit pitch changing operation of the propeller under the influence of the governor 33.

Should it be desirable to feather the propeller at any time, the switch arm 88 may be shifted to the "F" position noted which then connects the D. C. power source directly to a wire 90 leading to the wire 43 and thence either to the increase pitch clutch 18 or to the increase pitch winding of the motor 22 (depending on the position of the centrifugal switch 48) to increase the propeller pitch to the feather position without the intervention of any other part of the control system. When unfeathering of the propeller is desired, the switch arm 88 is moved from "F" to "N," restoring control of the propeller to the governor or to the blade angle control system, which will call for a blade angle in the operating range, and thus will cause decrease of blade pitch.

As has been noted previously, when the control lever

72 is moved between a vertical position as shown and a position to the right thereof, the propeller is placed under blade angle control and is freed from control by the governor 33. To this end, the switch lever 82 connects with the segment 84 whereby D. C. power from the breaker 89 is fed to a contact 92 of a blade angle relay 93. Contact 92 is engageable, under the action of a coil 94 of the relay 93, with an increase pitch contact 95 or a decrease pitch contact 96. The contact 95 is connected to the same portion of the limit switch set 30, 31 as is the increase pitch contact 42 while the contact 96 is connected to another bar 97 on the limit switch set 30, 31 connectible to the decrease pitch portions of the propeller pitch change mechanism through the switch 48.

In the coordinator unit 75 is a potentiometer winding 100 over which sweeps a contact 101 mounted on the axle 77 of the coordinator, so that the position of the contact 101 on the potentiometer winding is a function of the position of the power lever 72 when in the blade angle control range. That is, the position of the contact 101 will correspond to and will call for any pitch angle selected on the control lever 72. The ends of the winding of the potentiometer 100 are connected to an A. C. power source at 104 and to the ends of a second potentiometer winding 105 disposed adjacent the pitch angle indicating shaft 25. Upon this shaft is mounted a bevel pinion 106 meshing with a bevel pinion 107, the latter carrying a contact arm 108 engaging the potentiometer winding 105 in a position according to the actual blade angle of the propeller. The arm 108 is connected through a wire 109 to one end of the coil 94 of the blade angle relay 93, and the potentiometer arm 101 of the unit 75 is connected through a wire 110 with the other end of the coil 94 of the blade angle relay 93. If there is a blade angle error between that called for by the potentiometer 100 and that indicated by the potentiometer 105, a potential will be impressed upon the relay coil 94 in the appropriate direction, to move the relay contact 92 into engagement with the fixed contacts 95 or 96, thus connecting the power supply to the pitch changing mechanism. The blade angle relay 93 is preferably arranged with an amplifying unit so that small error voltages from the potentiometers will be built up to a sufficient extent to operate the contact 92 positively. The relay is further built to respond to either positive or negative potentials to cause the increase or decrease pitch circuits to be activated, and is so biased that the point 92 will remain in a disconnected position if there is no voltage imposed upon the relay coil 94. Relays of this type are commercially available and need not be described in detail.

From the foregoing description, it will be apparent that movement of the turbine control lever 72, as shown, in a leftward direction from the vertical places the propeller under the control of the governor, and that the governor speed is variable in accordance with lever position and will call for a desired scheduled R. P. M. Also, if the control lever 72 is moved rightwardly from the vertical position shown, a range of specific blade angles will be called for. The mechanism described enables the propeller to attain the desired preset blade angle through the potentiometer system and the mechanisms indicated.

Through an appropriately located control element such as 112, control lever 72 movements are transmitted to a turbine fuel control system. Such fuel control system does not form a part of the present invention and is known in the art. It may be assumed here that the rate of fuel feed to the engine is controlled through this instrumentality and such fuel rate is scheduled on a preset basis to yield a desired amount of engine torque for any desired R. P. M. or blade angle as called for by the control lever 72. The vertical position of the control lever 72 corresponds to an operating range called "flight idle." To the right of this vertical position is a position where zero blade angle would be called for, this being the position for starting of the turbine. Further to the right of the vertical position are blade angle positions in negative pitch in which range the turbine fuel feed would have definite values to enable operation of the turbine to produce reverse thrust through the propeller. To the left of the vertical position, increased fuel feed would be scheduled along with increased governed R. P. M. and after the top limit of governor R. P. M. is reached, continued increase of fuel feed would be scheduled to yield a reasonably wide range of power with the turbine operating at maximum R. P. M.

The system of Fig. 1 shows the control apparatus for a single turboprop installation, and the elements within the dot-dash line box at the right side of the figure are located in the pilot's compartment of the aircraft. For a multi-engine installation, there would normally be a single reference speed motor and generator to serve all power plants, including elements 68, 67, 60, and a single reset relay 62. Each power plant would have its own feather switch 87, coordinator 75 and blade angle relay 93, and its own power lever 72. The speed setting for the motor 67 is accomplished by the joint manipulation of the several power levers 72, the farthest advanced setting the speed level at which all will operate, except when some of them might be feathered or adjusted by respective power levers for blade angle control.

Each power plant would include all components shown within the solid lines at the left side of the figure, including a governor 33.

Reference should now be made to Fig. 2 which displays, in schematic fashion, the dual governor system which is contained within the governor unit 33 shown in Fig. 1.

Certain elements will be recognized from Fig. 1; namely, the three-phase power supply furnished from the generator 60 through wires 58 to a three-phase A. C. motor noted as 114. The alternative speed setting for the governor is conveyed thereto from the speed control rod 79 and the lever 80 to a rack 116 adjustable to compress a speeder spring 118 on a standby governor 120. Output from the governor 33 is at the shaft 34, this shaft being positioned according to the blade angle desired to attain the desired engine and propeller R. P. M. as dictated either by the motor 114 or the governor 120.

In this governor system, there are alternative speed references, the motor 114 being one and the governor 120 being the other. Reference speed from either source is applied to a shaft 122, while actual engine speed is applied through a shaft 124 driven by a suitable gear connection from the engine or propeller. Under normal operating conditions, the motor 114 drives the shaft 122, the drive connection comprising an internal gear 126 on the motor shaft. An axially translatable shaft 128 has a sliding spline connection 129 with the shaft 122 and is provided at its upper end, as shown, with a gear 130 which engages within the gear 126 at times, as a driving clutch. Through this connection, direct drive results from the motor to the shaft 122 when the gears 130 and 126 are engaged. The shaft 128 is embraced by a solenoid 132 which, when energized, holds the gears 130 and 126 in driving engagement. If electrical energization of the solenoid 122 ceases, a spring 134 urges the shaft 128 downwardly to disengage the gears 130 and 126 and to engage the gear 130 with a gear 136 driven from the standby governor as will be described. The solenoid 132 is connected to the D. C. power source through solenoid 65 of the reset relay 62 (Fig. 1), and through a series switch 138. The conductor from the solenoid 132 and switch 138 to the reset relay solenoid 65 is noted at 140 in both Figs. 1 and 2. Under normal conditions the switch 138 (Fig. 2) is closed and the reset relay (Fig. 1) is closed to complete a circuit from the wire 140, through a switch 142 of the reset relay, through the solenoid 65 and thence to the other terminal of the D. C. power source. Should a failure, momentarily or otherwise, occur in the speed regulation afforded by the A. C. motor 114, the switch 138 will open

as will be described, breaking the circuit to the solenoid **132** and allowing the governor drive to shift from the A. C. motor to the gear **136**. Upon opening of the switch **138**, energization of the relay solenoid **65** ceases, the switch **142** will open, and the A. C. motor **114** is rendered inactive until manual resetting of the relay **62**. Through this sequence, governor operation is transferred from the motor **114** as a reference speed source to the gear **136** as a reference speed source.

The auxiliary speed source at the gear **136** comprises one of the particular features of this invention. This governor consists of a shaft **146** driven by the engine which in turn drives a shaft **148** and the governor fly ball assembly **120** through gearing **149**. Upon incipient changes in speed of the engine, rotational speed of the governor assembly **120** varies, causing an axial shift of a rod **150** upon which is carried a cam **152** operating on the switch **138** and a grooved element **154** embracing a yoke **156**. The yoke **156** controls a small variable speed transmission **158**, the latter comprising a driving disc **160**, driven through gearing **162** from the shaft **148**. The disc **160** frictionally bears upon the surface of a ball **164** which is journaled to spin on a shaft **166** whose angular position is controlled by the yoke **156**. A driven disc **168** also frictionally engages the ball **164** and this disc drives a shaft **170** upon which the gear **136** is mounted. The bearing points of the discs **160** and **168** on the ball **164** are so arranged that when the ball axis **166** is in the position shown there will be a 1:1 drive ratio from the disc **160** to the disc **168**. When the ball axis **166** is tilted to one side or the other by the yoke **156** the drive ratio from the disc **160** to the disc **168** is changed so that the drive is either greater than 1:1 or less than 1:1. The governor balls **120** and the rod **150** control the drive ratio and, with the variable transmission, afford a means of maintaining constant speed of the driven disc **168** from the variable speed input at the disc **160**. For instance, if the disc **160** should droop in speed from the desired value, the balls of the governor **120** will move inwardly and the rod **150** will be shifted downwardly. This will tilt the ball axis **166** clockwise so that the disc **160** bears on a larger effective radius portion of the ball **164** while the disc **168** will bear on a smaller effective radius portion of the ball, thereby producing a step up in speed ratio from the disc **160** to the disc **168** and holding the disc **168** at substantially constant speed despite the reduction in speed of the disc **160**. As the speed of the disc **160** recovers to its normal value, the governor **120** will adjust the drive ratio of the transmission **158** so that the driven disc **168** will continue to run at constant speed.

The cam **152** which operates the switch **138** rotates at engine speed. Normally, the motor **114** is in operation to control engine speed. When engine speed drifts widely from the speed of the motor **114** or alternatively, if the motor **114** or part of its driving system fails, a substantial discrepancy will occur between engine speed and the desired speed as preset by the control lever **72** (Fig. 1) which is mechanically connected to calibrate the mechanical governor **120**. Thus, an unwanted speed deviation of the engine will move the cam **152** in an axial direction to open the switch **138** and thus cause shift of the speed control from the motor **114** to the mechanical governor **120** as previously described.

From the foregoing, it should be clear that the shaft **122** in the governor is at all times rotated at substantially constant speed. This shaft is connected to one face gear **174** of a differential **175**, the other face gear **176** of which is drivably connected through a shaft **177** to a disc **178** of a variable speed transmission unit **179** which is similar in character to the transmission **158**. This transmission includes another disc **180** which is engine driven from the shaft **124** and the discs **178** and **180** both frictionally engage the surface of a ball **181** which spins on a shiftable axis **182**, the axis **182** being angularly adjustable through a control lever **184**. Normally, if the engine is on speed, that is, at the desired speed as dictated by the reference speed shaft **122**, disc **178** will rotate at reference speed and the transmission **179** will be in 1:1 ratio. The face gears **174** and **176** of the differential **175** will rotate in equal and opposite directions and there will be no rotation of the differential spider, which carries a bevel gear **186**. Should there be a transient change in speed of the engine, or a change in R. P. M. required, this will be reflected in the shaft **177** since the transmission **179** is initially in 1:1 ratio. Thereupon, the gears **174** and **176** will no longer rotate equally in opposite direction but will rotate unequally in opposite directions to produce rotation of the spider bevel gear **186**. This produces rotation of a shaft **188** driven by the spider gear **186** in an amount representing the speed error. The shaft **188** is provided with a worm **190** operating on a worm wheel sector **192** connected by a rod **194** to the operating lever **184** of the variable speed transmission **179**. The rotation of the shaft **188** will then shift the ratio of the transmission **179** in a direction to erase the speed error—that is, to restore the speed of the shaft **177** to equality with the speed of the shaft **122**. This operation of course takes a small time interval and as the correction is applied, the rotational position of the shaft **188** will be different from that existing when the engine is on speed. The speed error represented by the shaft **188** is also applied through appropriate drive connections to a face gear **196** of a differential **198**, the differential having another face gear **200** connected in the system in a manner which will now be described.

Another differential **202** is provided with a face gear **204** driven through gearing and shafting **206** at constant speed from the shaft **122**. The differential **202** is also provided with a face gear **208** driven through appropriate shafting and gearing **210** from the engine driven shaft **124**, the rotation of the gears **204** and **208** being opposite. Should there be a speed error between the shafts **122** and **124**, this will be picked up in the differential **202** and the spider **212** thereof will be rotated, the rotation of this spider representing the integral of the speed error. The spider **212** is connected by gearing and shafting **214** to the face gear **200** of the differential **198**. A spider **216** of the differential **198** algebraically adds the errors represented by the face gears **196** and **200** and yields a direct mechanical signal to the governor output shaft **34** through a slip clutch **218** (provided for safety purposes). The position of the shaft **34** will then comprise the algebraic sum of the speed error and the integral of the speed error which is proportional to the actual blade angle which is desired at the propeller to produce engine and propeller speed in consonance with the reference speed. If the propeller is operating at the constant reference speed, the position of the shaft **34** will be such as to represent the particular blade angle at which the propeller is operating. If a speed error exists through readjustment of speed required or through transient phenomena which tend to alter engine speed and to deviate it from reference speed, the governor output shaft **34** will, in an extremely brief time interval, assume a new position representing blade angle required to produce synchronism of engine speed with desired speed.

Through the pitch changing mechanism already described, the governor output member **34** will cause the propeller to adjust pitch to the desired value.

The system described above, embodying the differentials **175**, **202** and **198**, and the variable speed transmission **179**, provides acceleration stabilization and promptly affords a setting for desired blade angle taking into account acceleration characteristics in the system. The system above described is also shown and described in Robbins application Serial No. 234,888 filed July 2, 1951 and mentioned heretofore.

In the mechanisms described in connection with Fig. 2,

the principal feature is the provision of alternative constant speed reference of mechanical character which is secured from a variable speed driving source. Those features of the arrangement in Fig. 2 which provide blade angle signals embodying acceleration stabilization are covered in the said Robbins patent application.

A further showing of one of the features of the invention is provided in Fig. 3, this comprising a simplification of a portion of the showing of Fig. 2 to indicate the obtaining of a constant speed reference signal from a variable speed source and the provision of an integrated speed error signal from the unit. In Fig. 3, engine speed is fed to the system at a shaft **224** which is carried to a driving disc **160'** of a variable speed transmission **158'**. Engine speed is also carried to a shaft **148'**, thence to a governor **120'** through gearing **149'**. The governor, like that shown in Fig. 2, is provided with a speeder spring **118'** and a rack **116'** to set desired speed level. In the transmission **158'**, a driven disc **168'** engages the transmission ball **164'**, the latter being adjustable in position by the governor rod **150'**, the grooved member **154'** and the yoke **156'**. The action of these elements is the same as that which has been described in connection with Fig. 2, the elements bearing the same reference characters, primed, so that the description in connection with Fig. 2 will serve to explain the functioning of the governor of Fig. 3. By the action of this system, the shaft **170'** operates at constant speed. The constant speed is compared with actual speed in a differential **226**, this differential being productive of an integrated speed error in the governor output element **228**. The differential **226** is equivalent to the differential **202** in Fig. 2 and the signal produced in the shaft **228** is equivalent to the signal produced at the differential face gear **200** in Fig. 2.

In the systems shown and described herein, schematic representations have been utilized to enable a clear understanding of the functions of the several arrangements and components. In actually reducing the invention to practice, the proportions and character of the various elements may be modified materially to produce a compact and effective mechanical device and it is assumed that the skilled designer will be able from the description herein to produce an effective mechanical governing system. It may be noted in Fig. 2 that some of the shafts in the governor system are interrupted by boxes bearing the letter G. These elements are representative of gear connections to provide fixed drive ratios between different elements to bring the speeds of the several elements into proper consonance with one another and to control the sensitivity of the various parts of the system to desired levels. The selection of the appropriate ratio relationships is deemed to be within the province of the skilled designer.

In connection with the propeller control diagram of Fig. 1, various changes and modifications may be made therein and again, the application of skillful design to the schematic system to secure a compact and effective operable article is applicable. In addition, the designer may superimpose on the system upon various additional functions and devices. For instance, a system may be incorporated for automatic feathering of the propeller in response to a lack of torque output from the turbine. Also, additional pitch limits and limit switches may be incorporated in the system to establish high and low reverse pitch limits and high and low normal pitch limits.

The pitch changing system of Fig. 1 is one in which the rate of pitch change during normal propeller operation is relatively high—of the order of 20° to 40° per second. This rate of pitch change is readily obtainable when the power of the turbine, in driving the propeller, is utilized to furnish the power necessary for changing pitch at high rates. The standby pitch changing system represented by the electric motor **22** is normally designed for low rate pitch change in order to minimize the size and weight of the auxiliary pitch changing motor. No criteria are indicated herein for the scheduling of turbine power or torque along with turbine and propeller R. P. M. since this sort of scheduling depends upon the individual characteristics of the turbine-propeller installation and of the aircraft in which such installation is used.

Though several embodiments illustrating the invention have been shown and described, it is to be understood that the invention may be applied in other and various forms. Changes may be made in the arrangements, without departing from the spirit of the invention. Reference should be had to the appended claims for definitions of the limits of the invention.

What is claimed is:

1. In a speed control for an engine driving a propeller having variable pitch blades and an adjustable blade pitch changing mechanism, a governor positively driven by the engine at a speed varying linearly as engine speed, said governor having an output member movable in response to speed deviations from the desired speed, a variable ratio transmission having an input member positively driven by the engine at a speed varying linearly as engine speed, having an output member and having a drive ratio changing means, an operating connection from said governor output member to said ratio changing means to alter transmission drive ratio in response to governor sensed speed error in a direction to maintain the transmission output member at substantially constant speed, means connected to said engine and to said transmission output member to compare engine speed with said constant speed productive of an engine speed error signal, and actuating means connected to said comparing means responsive to such speed error signals to operate said pitch changing mechanism to change propeller blade pitch.

2. In a speed control for an engine driving a propeller having variable pitch blades and an adjustable pitch changing mechanism, an engine speed responsive governor, means driving the governor from the engine at a speed proportional to engine speed a variable ratio drive transmission driven by the engine and having an output member, means operated by and responsive to the governor as it senses engine speed errors to alter the drive ratio of said transmission in a direction to maintain the transmission output substantially at constant speed, means connected to the engine and to said output member to compare engine speed with said constant speed productive of a speed error signal, and actuating means connected to said comparing means responsive to such speed error signal to operate said pitch changing mechanism to change propeller blade pitch, said comparing means including mechanism responsive to acceleration of the engine to produce an acceleration signal and to superimpose the acceleration signal on the speed error signal.

3. In an engine speed governing system, means to vary engine speed, a governor positively driven by the engine at a speed varying linearly as engine speed and having an output member movable in response to speed deviations from a desired speed, a variable speed transmission having an input member positively driven by the engine at a speed varying linearly as engine speed, means actuated by said governor output member controlling transmission drive ratio, said transmission having an output member, and means driven by said engine and by said transmission output member to compare engine speed and transmission output speed, said comparing means having an output element connected to and movable to operate said engine speed varying means.

4. In an engine speed control system, a first speed reference comprising an adjustable constant speed device, an output element clutchable thereto, an engine speed element, means connected to said elements to compare the

speeds of said elements productive of a speed error signal, means connected to said comparing means responsive to speed error signals to correct engine speed; a second speed reference comprising an engine driven variable speed transmission said transmission having an output, a governor driven by the engine and connected to said transmission responsive to engine speed and operable to adjust said transmission to maintain substantially constant transmission output speed, and means connected to said output element to clutch the transmission output to said output element concurrently with the de-clutching of said first speed reference therefrom.

5. In an engine speed control system, a first speed reference comprising an adjustable constant speed device, an output element clutchable thereto, an engine speed element, means connected to said elements to compare the speeds of said elements productive of a speed error signal, means connected to said comparing means responsive to speed error signals to correct engine speed; a second speed reference comprising an engine driven variable speed transmission said transmission having an output, a governor driven by the engine and connected to said transmission responsive to engine speed and operable to adjust said transmission to maintain substantially constant transmission output speed, and means connected to said output element to clutch the transmission output to said output element concurrently with the de-clutching of said first speed reference therefrom, said first speed reference comprising an electric motor, and means connected to said governor responsive to failure of the electrical system to shift said clutch means and to shift said output element from drive by the electric motor to drive by the second speed reference.

6. In an engine speed control system, a unit comprising a variable ratio transmission including an input member driven positively by and at a speed linearly proportional to that of the engine, said transmission having an output member, means actuated by said transmission output member connected to alter the speed of said engine, a governor connected to and positively driven by said engine at a speed linearly proportional to engine speed, productive at times of a speed error signal, and means operated by a speed error signal from the governor connected to said transmission for varying the drive ratio thereof.

7. In an engine speed control system, a unit comprising a variable ratio transmission including an input member driven positively by and at a speed linearly proportional to that of the engine, a three element differential having one input element thereof positively driven by the engine at a speed proportional to engine speed, said transmission having an output member positively driveably connected to a second element of said differential, the third differential element comprising an output element operating at a speed representing the difference between engine speed and transmission output speed, means operated by said third differential element to control the speed of said engine, a governor connected to and positively driven by said engine at a speed linearly proportional to engine speed, and means operated by a speed error signal from the governor connected to said transmission for varying the drive ratio thereof.

8. In an engine speed control system, a unit comprising a variable ratio transmission connecting means driving said transmission from the engine at a speed proportional to engine speed, a three-element differential having an input driven by the engine at a speed proportional to engine speed, a centrifugal governor connected to and driven by the engine at a speed proportional to engine speed, means connected to and operated by said governor to adjust the ratio of said transmission, an input driven by the transmission output and an output for the differential representing the difference between transmission output speed and engine speed, means connected to said differential to derive the rate of change of speed of said output, means connected to said differential and to said driving means to add the speed of said output and the rate of change thereof to produce a corrective signal, and means connected to said adding means operated by a finite corrective signal to alter and correct the speed of the engine.

9. In an engine control system, mechanism to change engine speed, a first speed reference source, a second speed reference source, a member engageable with either speed reference source for drive thereby and normally engaged with the first of them, said engine speed normally corresponding to the speed of said first speed reference source, means connected to said member actuated by a material drift of engine speed from the desired speed for shifting said member from engagement with the first of said speed reference sources to the second thereof, means operated by and connected to said engine and the active speed reference source through said member for comparing engine speed and speed of said member, and means connected to and actuated by said comparing means to operate the said engine speed changing mechanism.

10. In an engine control system, mechanism to change engine speed, a first speed reference source, a second speed reference source, a member engageable with either speed reference source for drive thereby and normally engaged with the first of them, said engine speed normally corresponding to the speed of said first speed reference source, means connected to said member actuated by a material drift of engine speed from the desired speed for shifting said member from engagement with the first of said speed reference sources to the second thereof, means operated by and connected to said engine and the active speed reference source through said member for comparing engine speed and speed of said member, and means connected to and actuated by said comparing means to operate the said engine speed changing mechanism, said speed changing mechanism comprising a controllable pitch propeller.

11. In turbine-propeller power plant control system including a controllable pitch propeller and pitch changing mechanism therefor, means movable to any one of a plurality of positions to call for any one of a plurality of specific desired blade angle settings of the propeller between a reverse pitch blade angle and a small positive blade angle, means actuated by movement of said movable means to initiate operation of said pitch changing mechanism to bring about pitch change, means responsive to attainment of the called-for angle by the blade to terminate operation of said pitch changing mechanism, an adjustable speed governor connected to and driven by said power plant having an output element which calls for that blade angle change necessary to attain a desired speed, means connecting said governor output element to said pitch changing mechanism to initiate operation thereof in the direction of the governor called for pitch change, means to stop operation of said pitch change mechanism upon the blade having accomplished the blade angle change called for by the governor, a control member having two separate but substantially contiguous ranges of movement, a first range for selection of any one of a plurality of blade angles according to member position, and a second range for selection of governor speed setting adjustment, means connecting said control member to operate said movable means in response to positioning of the member in the first range, and means connecting said control member to operate the speed adjustment of said governor in response to positioning of the member in said second range.

12. In a turbine power plant control system including a controllable pitch propeller having a pitch changing mechanism operable to change propeller pitch, a member movable to any one of a plurality of blade pitch angle settings between reverse pitch and a small positive forward pitch, means responsive to movement of said member to initiate mechanism operation in a direction to cause blade pitch to change to the setting of said member,

means responsive to attainment of the blade pitch set by said member to terminate pitch changing operation of said pitch changing mechanism, a power plant driven governor having a variable desired speed setting and means to adjust the set speed thereof, said governor having an output element movable in response to speed error between the power plant speed and the set speed of the governor, an operating connection between said governor output element and said pitch changing mechanism operable to cause mechanism operation in response to a speed error sensed by said governor and in a direction to erase said speed error, a manually operated control member having a first range movement and a second range movement, said ranges being contiguous, means operatively connecting said control member when in the first range of movement to said movable member, said operatively connecting means establishing a linear connection whereby control member movement and movable member movement will be proportional, and means operatively connecting said control member when in the second range of movement to said governor setting means whereby control member movement will control governor setting in accordance with the position of said control member in said second range.

13. In a turbine-propeller power plant control system including a controllable pitch propeller, pitch changing mechanism including control elements movable to several positions to select propeller blade pitch angle and including power means actuated by the control elements to cause the propeller blades to move to the selected pitch angle, a control member manually adjustable within and between two operating ranges, the first of said ranges being calibrated for a plurality of specific blade angles between reverse pitch and a small positive blade angle and the second being calibrated for a plurality of desired operating rotational speeds of the power plant, means connected to and actuated by said member and in response to positioning thereof in said first range to connect the member for operation of said blade angle control elements, a speed governor drivably connected to the power plant having a desired speed adjuster and an output element positioned by the governor according to its setting to call for blade pitch angle appropriate for the desired speed and turbine power, means connected to and actuated by said control member and in response to positioning thereof in said second range to connect the member to the governor speed adjuster and to connect the governor output element to operate the blade angle control elements, said governor comprising an element driven at a turbine-proportional speed, an element driven at a speed proportional to desired speed as preset by the control member, and means to compare said speeds productive of a speed error signal; and means connected to said governor and to said pitch changing mechanism actuated by said speed error signal to convert the signal into motion corresponding to desired blade angle.

14. In a turbine-propeller power plant control system including a controllable pitch propeller, pitch changing mechanism including control elements movable to several positions to select propeller blade pitch angle and including power means actuated by the control elements to cause the propeller blades to move to the selected pitch angle, a control member manually adjustable within and between two operating ranges, the first of said ranges being calibrated for a plurality of specific blade angles between reverse pitch and a small positive blade angle and the second being calibrated for a plurality of desired operating rotational speeds of the power plant, means connected to and actuated by said member and in response to positioning thereof in said first range to connect the member for operation of said blade angle control elements, a speed governor drivably connected to the power plant having a desired speed adjuster and an output element positioned by the governor according to its setting to call for blade pitch angle appropriate for the desired speed and turbine power, means connected to and actuated by said control member and in response to positioning thereof in said second range to connect the member to the governor speed adjuster and to connect the governor output element to operate the blade angle control elements, said governor comprising an element driven at turbine-proportional speed, an element driven at a speed proportional to desired speed as preset by the control member, and means to compare said speeds productive of a speed error signal; means connected to said governor productive of a signal as a function of the rate of change of speed of the turbine, and means connected to said governor and to said ratio signal means combining said two signals said latter means being connected to drive said governor output element.

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