

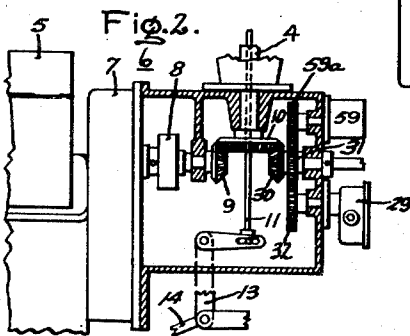
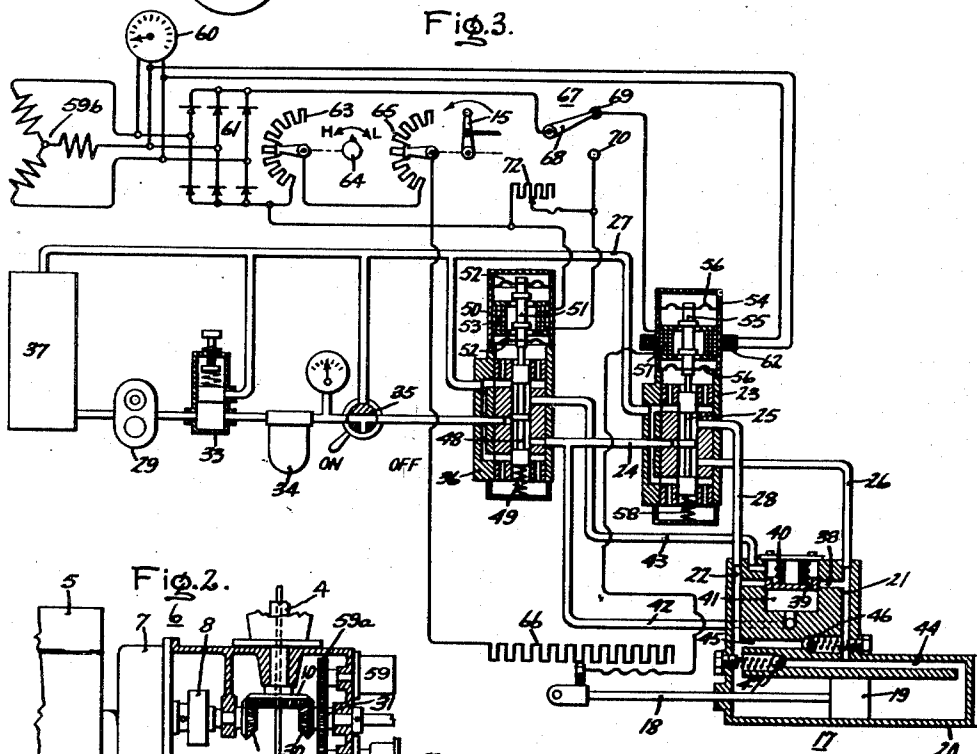
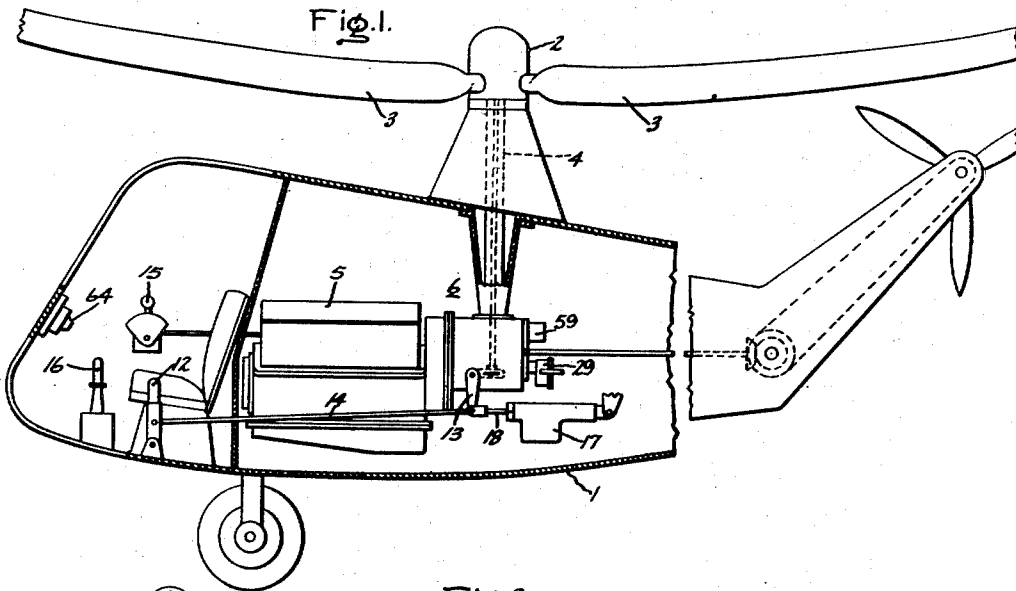
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GOVERNOR

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GOVERNOR

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The present invention relates to aircraft control, and more particularly to a system for controlling the speed and pitch of the rotor of a helicopter or other rotary wing aircraft.

Helicopters are usually provided with a powered lifting rotor or rotors having a plurality of blades which are hinged to the rotor hub to permit vertical movement or coning. The blades are also mounted so that they can be rotated to adjust the pitch so that the lifting effort of the rotor or rotors can be controlled. In flight, the lifting force exerted on the blade tends to pivot the blade upwardly but this upward movement is opposed by the centrifugal force of the blades which tends to keep them in an extended position. It is very important in flight that the speed of the rotor be kept above a minimum safe value to prevent the blades from collapsing or stalling. On the other hand, it is important that the speed of the rotor be kept below a maximum safe value to keep the centrifugal force from stressing the rotor parts beyond design limitations. In order to keep the rotor speed within safe limits, it is necessary in autorotational flight to adjust the pitch of the blades and in powered flight it is necessary to coordinate both the pitch of the blades and the power output of the driving motor. This coordination problem, if done manually, is not only burdensome to the pilot, but may result in a serious crash if not performed quickly and properly. Therefore, it is desirable that means be provided for accomplishing this coordination automatically.

Heretofore, two different rotor speed-governing systems have been proposed for solving this problem. In one system, referred to as a throttle governor, the throttle of the drive motor unit is adjusted in accordance with the speed of the rotor to keep a constant motor and rotor speed, and the lift of the rotor is then controlled by varying the rotor pitch. In the other system, referred to as a pitch governor, the pitch of the rotor is adjusted in accordance with the speed of the rotor to keep approximately constant rotor speed and the lift of the rotor is controlled by varying the motor throttle.

The throttle governor has the advantage that the lift of the rotor is immediately responsive to movement of the manually operated pitch control so that maneuvering, especially near the ground, is facilitated and, if necessary, the kinetic energy stored in the rotor can be utilized to provide additional momentary lift. The throttle governor has the disadvantage that the governing system is exceedingly difficult to stabilize due

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to the relatively slow response of an internal combustion engine to an opening of the throttle.

The pitch governor has the advantage that it is easier to stabilize the governing system. It has an additional very important advantage that it may be made to automatically reduce the rotor pitch in case of engine failure during powered flight. A difficulty with the present pitch governing systems is that the vertical lift response of the helicopter to movements of the throttle is very sluggish, making maneuvering operations difficult.

An object of the present invention is to provide a pitch governor for controlling the speed of a helicopter rotor which has the desirable features of both the throttle and pitch governing systems without the above-mentioned disadvantages.

A further object is to provide a rotor speed-governing system which is fast acting without sacrificing stability of operation.

Another object is to provide a rotor pitch governor for a helicopter which responds quickly to a movement of the engine throttle to change the rotor lift.

A still further object of the invention is to provide a helicopter rotor pitch-governing system which can be operated either manually or automatically and which will operate automatically to reduce the pitch of the rotor if the speed of the rotor falls below a minimum safe value while under either manual or automatic control.

Another object is to provide a pitch governor which is fail-safe; i. e., one which will disconnect the governing mechanism in case of failure of component parts of the governor.

Further objects and advantages of the invention will become apparent as the following description proceeds.

Briefly, according to the present invention, an electrically controlled servo system is provided for adjusting the pitch of the sustaining rotor blades in accordance with the speed of the rotor to maintain substantially constant rotor speed, the system, basically, falling into the category of the pitch governor system referred to above. However, in order to make the pitch of the blades immediately responsive to a change in throttle position to facilitate maneuvering, means controlled by the throttle are provided for causing operation of the servo system independently of the speed of the rotor so that the pitch of the rotor blades is adjusted in a direction to anticipate a change in rotor speed due to the changed power output of the driving motor as controlled by the position of the throttle. In this manner,

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transient changes in the speed of the rotor which would otherwise occur while the speed governing system was operating are avoided or greatly reduced and the lift of the rotor becomes quickly responsive to a change in throttle position. This prevents a sluggish response condition previously found to exist in pitch governing systems due to the fact that when the power of the driving motor was suddenly increased, as by opening the throttle, a considerable portion of the power was momentarily absorbed by the rotor in increasing the kinetic energy of the rotor due to the speed transient which is in a direction of increased R. P. M. when the power of the drive motor is increased. In addition, switching means are provided for rendering the pitch control servo system inactive for manual control of the pitch of the rotor when it is desired. However, if during manual operation the pilot inadvertently increases the pitch of the rotor to a point where the rotor speed falls below a minimum safe value, means are provided for automatically rendering the servo system active to change the pitch of the blade to the minimum pitch position. In this manner, the possibility of a crash due to low rotor speed and a resulting collapsing or stalling of the blades is precluded in manual as well as in automatic control of the rotor pitch.

For a better understanding of the present invention, reference should be made to the following description taken in connection with the accompanying drawings in which Fig. 1 shows a conventional helicopter to which the present invention may be applied; Fig. 2 is a more detailed view of the rotor drive transmission showing an arrangement by which the speed responsive tachometer and the oil pump, forming a part of the servo control system, are geared to the rotor drive shaft; and Fig. 3 shows in schematic form the servo control system embodying the present invention.

Referring now to the drawing, there is shown in Fig. 1 a conventional helicopter 1 to which the governing system forming the subject matter of the present invention may be applied. It should be clearly understood, however, that my invention is not limited to this type helicopter but has application to rotary wing aircraft generally. The helicopter is shown as being provided with a lifting or sustaining rotor comprising a rotary hub 2 which is mounted on the helicopter for rotation about an approximately vertical axis. Radially extending from the hub 2 are a plurality of lifting blades 3 which are secured to the hub by a conventional hinging arrangement not shown. The hinging arrangement permits the blades to flap up and down as they rotate in order to compensate for the difference in the relative air speed of the blades when they are in the advancing and receding positions during horizontal flight. The conventional hinging and mounting arrangement of the blades also permits the blades to be rotated about an axis extending lengthwise of the blades so that the total pitch and lift of the blades can be varied.

The rotor has a drive shaft 4 which is power-driven by means of an internal combustion engine 5 through a transmission indicated generally at 6. As shown more clearly in Fig. 2, the transmission may comprise a gear-reduction unit 7, a free-wheeling clutch 8, and a bevel gear 9 for transmitting power from the internal combustion engine 5 to a bevel or ring gear 10 which is secured to the lower end of the rotor drive shaft 4. The free-wheeling clutch 8 is usually pro-

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vided in helicopters to disconnect the rotor from the driving motor in case of motor failure so as to permit a safe autorotational descent.

In the illustrated arrangement, the total pitch of the rotor blades is adjusted by means of a vertically moving shaft 11 which extends upwardly to the pitch changing mechanism (not shown) in the rotor hub 2 through the inside of the rotor shaft 4 which is hollow. The pitch control shaft 11 is coupled to a pivotally mounted pitch control lever 12 in the pilot's compartment by means of a linkage shown as comprising a bell crank 13 and a connecting link 14. Clockwise rotation of the pitch control lever 12 causes the pitch changing shaft 11 to move upwardly, which is in a direction to increase the pitch of the blade 3. Similarly, a counterclockwise rotation of the pitch control lever 12 causes a downward movement of the shaft 11 and a decrease in the pitch of the blades.

Also provided in the pilot's compartment is a throttle lever 15 which varies the power output of the internal combustion engine or driving motor 5. The connection is such that a forward or counterclockwise movement of the throttle lever 15 acts to increase the power output of the driving motor 5. In some cases the throttle is in the form of a motorcycle type grip mounted on the upper end of the pitch control lever 12.

Usually the pilot has under his control an additional cyclic pitch control lever 16 by means of which horizontal flight of the helicopter is controlled. This control acts cyclically to vary the pitch of the blades as they rotate. Since the cyclic pitch control forms no part of the present invention, a description thereof will be omitted. It should be pointed out, however, that the cyclic pitch change of the rotor blades used to control horizontal flight is different and entirely separate from the simultaneous pitch change of the rotor blades which is used to control the vertical lift of the rotor and the vertical flight of the helicopter. It is in connection with the simultaneous pitch control that the present invention is concerned.

In the absence of an automatic pitch-governing mechanism, the pilot controls the vertical flight of the helicopter by a coordinated movement of the throttle lever 15 and the pitch control lever 12. Thus, for example, if the pilot desires the helicopter to rise, he moves the throttle lever 15 forward to increase the power output of the drive motor 5 and at the same time moves the pitch control lever 12 backward to increase the pitch and lift of the rotor. Similarly, if the pilot desires the helicopter to descend, he pulls the throttle lever 15 backwards and moves the pitch control lever forward to decrease the pitch and lift of the rotor. It will be appreciated that if the throttle lever and pitch control lever are not properly coordinated, the speed of the sustaining rotor may exceed the maximum safe value or may fall below the minimum safe value, in which case serious difficulty will be encountered as pointed out above.

The governing system, forming the subject matter of the present invention, is a means whereby the pitch of the rotor blades 3 is automatically adjusted in accordance with the speed of the rotor so as to maintain the rotor speed approximately constant at some value which is within the safe operating range.

In order to provide means for automatically actuating the pitch changing mechanism in accordance with the speed of the rotor and the

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position of the throttle lever, there is provided a suitable servomotor 17 which may, for example, be a hydraulic push-pull type. As shown, the hydraulic servo 17 comprises an actuating shaft 18 which is coupled to a servo piston 19 which moves in response to the admission of hydraulic fluid under pressure to either end of the servo cylinder 20 through passages 21 and 22 which are connected to opposite ends of the cylinder. The actuating shaft 18 of the servomotor is shown as being coupled to the lower end of the bell crank 13 so that as the shaft 18 moves outwardly the pitch of the rotor blades is decreased, and as the shaft moves inwardly the pitch of the rotor blades is increased. The direction of movement of the servomotor 17 is controlled by means of a control valve 23 which operates to connect a hydraulic pressure line 24 to either passage 21 or 22 of the hydraulic servo in accordance with the direction of vertical displacement of a three-land valve element 25 from a center or neutral position. Thus, when the valve element 25 is in the center position shown, the port connected to the pressure line 24 is closed and the servomotor 17 remains stationary. If, however, the valve element 25 is moved upwardly, the pressure line 24 is connected to a line 26 leading to the passage 21 of the hydraulic servo causing the shaft 18 to move outwardly, the displaced oil in the servo cylinder returning to a drain line 27 through a line 28 interconnecting the valve 23 and the passage 22. On the other hand, if the valve element 25 is displaced downwardly from the center position, hydraulic fluid from the pressure line 24 flows through the valve 23 and the line 28 to the passage 22 and into the opposite end of the servo cylinder, causing the shaft 18 to move inwardly, the displaced oil on the opposite side of the piston 19 returning to the drain line 27 through the line 26 and the valve 23. The porting arrangement of the valve 23 whereby the hydraulic oil is admitted to either end of the servo cylinder 20 of the hydraulic servo 17 in accordance with the displacement of the valve member 25 from its center or neutral position is entirely conventional and will be readily apparent from an inspection of the drawing.

Any suitable hydraulic operating fluid, such as hydraulic oil, is supplied to the pressure line 24 by means of a suitable hydraulic pump 29 which may, for example, be a gear-type displacement pump. The pump 29 is driven from the rotor shaft 4 so that the servo system will continue to operate in case of engine failure. Thus the pump 29 is shown as being geared to the bevel gear 10 on the rotor shaft 4 through a gear train comprising a bevel gear 30 and spur gears 31 and 32. The gears 30 and 31 may be, as shown, mounted on the shaft which drives the counter-torque propeller located at the rear of the helicopter.

The discharge or outlet of the oil pump 29 is shown as being connected to the pressure line 24 by a hydraulic circuit which includes a relief valve or pressure regulator 33, an oil filter 34, a manually operated "on-off" valve 35, and a normally open, electrically operated control valve 36. The inlet or intake of the pump 29 is connected to the lower portion of a suitable reservoir or sump 37, the upper portion of which is connected to the drain line 27 so as to complete the hydraulic fluid circuit.

The hydraulic servo 17 is normally locked when the control valve element 25 is in the center position. In order to provide means for freeing the servo piston for manual operation of the pitch

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control, there is provided in the hydraulic servo a by-pass passageway 38 which normally connects the opposite ends of the servo cylinder. The by-pass passageway 38, which is normally open, is arranged to be closed by means of a piston 39 which moves upwardly to the position shown against the bias of a spring 40 in response to the application of hydraulic pressure to a chamber 41 on the underside of the piston 39. The chamber 41 is connected to the pressure line 24 by means of a line 42 so that when there is pressure in line 24, piston 39 is moved upwardly and the by-pass is closed, thereby conditioning the hydraulic servomotor for control in accordance with displacement of the valve element 25 of the control valve 23. However, upon a failure of pressure in the conduit 24, the spring 40 moves piston 39 downwardly, opening the by-pass passage 38 so that the servo piston is freed. Trapped oil on the upper side of the piston 39 is returned to the drain line 27 through a line 43 and the control valve 36.

Thus it will be apparent from the foregoing that if the oil pressure fails in line 24 due to a closing of the manually operated valve 35 or a closing of the electrically operated valve 36, the servo piston will be freed for manual operation of the pitch controller in response to movements of the pitch control lever 12. However, to provide against some emergency condition in which it would be impossible to turn off the pressure supplied to line 24, there are provided additional by-pass passages 44 and 45 in the hydraulic servo which also interconnect opposite ends of the servo cylinder. The passages 44 and 45 are normally closed by spring-pressed ball check valves 46 and 47 which open to permit passage of hydraulic fluid between the opposite ends of the servo cylinder in response to application of abnormally high hydraulic pressures. Thus in the case of an emergency, the shaft 18 of the hydraulic servo can be moved in either direction by the application of sufficient overpowering force to the pitch control lever 12 so that in no case is there any danger of the pitch control system being locked by the hydraulic servomotor.

Electrically operated control valve 36 is provided for the purpose of engaging or disengaging the hydraulic servomotor 17. The construction of the valve may be the same as the control valve 23 previously described, and comprises a conventional three-land valve element 48 which moves vertically in either direction from a center or neutral position. The valve 36 is suitably ported so that when the valve member 48 is in the upper position shown, the pressure line 24 is connected to the output of the oil pump 29 so that the control valve 23 is supplied with oil and the piston 39 moves upwardly to close the by-pass passage 38 to render the hydraulic servomotor active. In this position ports are also open so that oil trapped on the upper side of piston 39 can return to the drain line 27 through the line 43. However, if the valve member 48 is moved downwardly, oil pressure is cut off from the line 24 which is then connected to the drain line 27, and oil pressure from the pump 29 is directed through line 43 to the upper side of piston 39 in the hydraulic servo, forcing the piston downwardly so as to open the by-pass passage 38, thereby rendering the hydraulic servo inactive. Normally the valve member 48 is maintained in the upper position shown by means of a biasing spring 49 so that the hydraulic servo and its control valve 23 are conditioned for

operation. In order to move the valve element 48 downwardly to disengage the hydraulic servo in response to an electrical signal, there is provided an operating solenoid 50 which is mounted on the upper side of the valve 36. The solenoid 50 comprises a plunger or armature member 51 which is supported for vertical movement on spider springs 52, the lower end of the plunger bearing against the top of the valve element 48. Surrounding the armature 51 is a solenoid-operating winding 53 which when energized acts to pull the armature downwardly so that the valve element 48 is moved to its lowermost position against the bias of spring 49. The manner in which the solenoid winding 53 is energized to effect operation of the control valve 36 will be later described.

The control valve 23 which controls the direction of movement of the servomotor 17 is operated by means of a solenoid 54, mounted on the top side of the valve which may be, as shown, of the same general construction as the solenoid 50 of the control valve 36. Thus the solenoid 54 is shown as comprising a plunger or armature member 55 which is supported for vertical movement on spider springs 56, which support the armature so that the lower portion thereof bears against the top of the valve element 25. Surrounding the plunger 55 is a solenoid-operating winding 57 which when energized acts to pull the armature downwardly and thereby move the valve element 25 to its lowermost position against the force of a biasing spring 58 which bears upwardly against the bottom of the valve element 25. The movement of the plunger 55 varies in accordance with the amount of current flowing in the operating winding 57 so that by varying the current in the operating winding the position of the valve element can be controlled. Thus when the current in the operating winding 57 has a relatively low value, the valve element 25 moves upwardly causing the shaft 18 of the hydraulic servo to move outwardly to decrease the pitch of the rotor blades. On the other hand, if the current in the operating winding of the solenoid is increased to a relatively high value, the valve element 25 moves to its lowermost position causing an inward movement of the shaft 18 of the hydraulic servo and an increase in pitch of the rotor blades. At some balance value of current flowing in the operating winding of the solenoid 54, the valve element 25 will remain in the center position and the hydraulic servo will be stationary.

In order to adjust automatically the pitch of the rotor blades in accordance with the speed of the rotor so as to maintain approximately constant rotor speed, means are provided for varying the current flowing in the operating winding 57 of the solenoid 56 in accordance with the rotor speed. This is accomplished by supplying current to the operating winding 57 from a tachometer generator 59 which is geared to the rotor drive shaft 4 so as to be driven at a speed proportional to the rotor speed. Thus, as shown in Fig. 2, the tachometer generator 59 has mounted on its drive shaft the spur gear 59a which meshes with spur gear 31, which also drives the oil pump 29 as has been previously described.

The tachometer generator 59 is illustrated as being a three-phase alternating current type, the three-phase stator output windings being indicated at 59b in Fig. 2 of the drawing. Such a tachometer generator is usually already available on a helicopter to indicate rotor speed on a

frequency responsive tachometer indicator, shown at 60, which is usually mounted on the control panel of the pilot's compartment to indicate rotor speed.

As shown in the drawing, the energizing circuit for the solenoid winding 57 of the solenoid-operating control valve 23 is electrically connected to the three-phase output winding 59b of the tachometer generator 59 by a circuit which includes a three-phase rectifier 61. Therefore, direct current is supplied to the operating winding 57 which is proportional to the voltage output of the tachometer generator 59 which is in turn proportional to the speed of the rotor. In this manner, the position of valve element 23, and consequently the direction of movement of the hydraulic servomotor 17 and the pitch of the rotor blades, is varied in a direction to maintain a rotor speed which corresponds to the current in the operating winding 57 which maintains the valve in the center position.

In order to make the solenoid 56 very sensitive to changes in current flowing in the operating winding 57, an additional operating winding 62 surrounding the armature 55 may be provided. As shown, the winding 62 is directly connected to one of the phases of the tachometer generator output, the connection being made ahead of the rectifier 61 so that alternating current flows in the winding 62. This causes the armature 55 to oscillate so that the effective static friction of the valve element 23 is largely overcome, whereupon the valve is very sensitive to changes in current in the operating winding 57.

For the purpose of adjusting the rotor speed maintained by the governing system, there is provided a rheostat 63 which is connected in series circuit relation in the energizing circuit of the solenoid winding 57. By adjusting rheostat 63, it will be apparent that the voltage output of the tachometer generator 59, and consequently the rotor speed required to center the control valve 23, can be adjusted as desired. The position of rheostat 63 may be conveniently adjusted by a control knob 64 which may be placed, as shown, in the pilot's compartment and thereby provide a simple adjustment whereby the pilot may control the governed rotor speed.

It will be apparent that the governing system thus far described is essentially a rotor pitch governor which adjusts the pitch of the rotor blades in accordance with the speed of the rotor so as to maintain approximately constant rotor speed. Such a system, without further additions, is subject to the above-mentioned disadvantage that the lift of the rotor is not immediately responsive to a change in the position of the throttle 15 so that maneuvering is rendered difficult, particularly when the maneuvering is close to the ground or close to any object which must be cleared by a precise control of the vertical position of the helicopter. Thus, for example, if the throttle 15 is suddenly opened, no controlling action takes place until the speed of the rotor is increased sufficiently so that the solenoid 56 moves the valve element 25 downwardly to cause the actuating shaft 18 of the hydraulic servo to move inwardly and increase the pitch to reduce the rotor speed. This momentary speed transient, which is in a direction of increased R. P. M. of the rotor, results in a momentary absorption of a considerable amount of the increased power output of the internal combustion engine 5, which power is used in increasing the kinetic

energy of the rotor. When the throttle is closed, a reverse action takes place and a speed transient occurs in the direction of decreased R. P. M., which is required to effect a reduction in the pitch of the blades and the kinetic energy of the rotor tends to maintain the rotor lift momentarily after the throttle is moved towards the closed position. Therefore, it will be apparent that the rotor lift will respond in a sluggish manner to a change in throttle position which is undesirable for maneuvering. In order to overcome this difficulty, means are provided for causing the hydraulic servomotor 17 to respond immediately to a change in position of the throttle 15 so as to change the pitch of the rotor blades in a direction to anticipate a speed change of the rotor caused by a change in the power output of the driving motor 5. In the illustrated arrangement, this is accomplished by the provision of a rheostat 65 which is connected in series circuit relation in the energizing circuit of the solenoid winding 57 of the control valve 23. The resistance-adjusting arm of the rheostat 65 is mechanically coupled to the throttle lever 15 so that as the throttle is moved in a counterclockwise or forward direction to increase the power output of the motor 5, the resistance in the solenoid-energizing circuit is decreased. This causes the plunger 55 and the valve element 25 to move downwardly whereupon the actuating shaft of the servomotor 18 moves inwardly which is a direction to increase the pitch of the rotor blades whereby transient overspeeds are prevented. Similarly, if the throttle is moved in a clockwise or closing direction, the rheostat 65 increases the resistance of the solenoid energizing circuit and thereby decreases the current flowing therein. This causes the plunger 55 and the valve element 25 to move upwardly, whereupon the actuating shaft 18 of the servomotor moves outwardly which is in a direction to decrease the pitch of the rotor blades, whereby the transient underspeed is prevented.

In order to limit the travel of the hydraulic servomotor and the resulting change in pitch of the rotor blades in response to a movement of the throttle lever to an amount which is proportional to the movement of the throttle lever, and also to prevent a change in the governing speed which would otherwise be caused by the operation of the throttle-controlled rheostat 65, there is provided an additional rheostat 66 which is also connected in series circuit relation in the energizing circuit of the solenoid 57. The adjusting arm of the rheostat 66 is connected to be operated by the actuating shaft 18 of the hydraulic servomotor 17 in such a manner that when the shaft 18 moves outwardly to decrease the rotor pitch, the resistance of rheostat 66 is decreased and vice versa. The action is such that when the throttle 15 is moved, for example, in a direction to increase the power output of the motor 5, the resistance of the solenoid-energizing circuit is decreased, causing the servomotor shaft 18 to move inwardly as explained above. However, as the shaft 18 of the servomotor moves inwardly, rheostat 66 operates to increase the resistance of the energizing circuit whereupon the solenoid plunger 55 and the control valve element 25 are restored to the center or balanced position, thereby stopping movement of the servomotor. If the throttle lever 15 is moved in opposite direction to decrease the power output of the driving motor 5, it will be apparent from the foregoing that the reverse action will take place. Therefore the servomotor-operated rheostat 66 acts to limit the

movement of the servomotor in response to a movement of the throttle in an amount proportional to the movement of the throttle. The rheostat 66 also operates to maintain approximately constant the resistance in the energizing circuit of the solenoid 57 so that the control point speed of the governing system is not appreciably changed by operation of the throttle controlled rheostat 65. It should be understood that the positioning of the hydraulic servomotor in response to the movement of the throttle 15 does not interfere with additional positioning of the hydraulic servomotor and pitch of the rotor blades in accordance with the output of the tachometer generator 59 and the speed of the rotor. Therefore, if the speed of the rotor tends to change after the throttle setting has been varied, the solenoid-operated control valve 23 will respond to a change in current of the energizing circuit caused by a change in the output of the tachometer generator 59 to additionally adjust the position of the servomotor and the pitch of the rotor blades to maintain constant the rotor speed. Thus the throttle-operated rheostat 65 and the servomotor-operated rheostats 66 may be considered as a follow-up system for positioning the servomotor in accordance with the position of the throttle, this action being superimposed upon the speed-regulating action of the governor as controlled by the output of the tachometer generator 59.

The servomotor operated rheostat 66 also performs a very desirable additional function of stabilizing the governor when it operates to change the pitch of the rotor blades in response to a change in voltage output of the tachometer generator. Thus, for example, if for some reason the speed of the rotor should fall below the set value, the output of the tachometer generator 59 and the current flowing in the solenoid winding 57 will decrease, thereupon the valve element 25 will move upward to cause the servomotor to move outwardly to decrease the rotor pitch. This causes the rheostat 66 to decrease the resistance and therefore increase the current in the energizing circuit of the solenoid 57 so that it returns to the center or neutral position quicker than would otherwise be the case. This action tends to preventing hunting of the servomotor, whereupon more stable governor operation is obtained particularly when a fast acting, sensitive control valve 23 is used to obtain rapid pitch change adjustment.

As pointed out above, the solenoid-operated control valve 36 operates when energized to disable the servo system. Therefore, when it is desired to operate the pitch control manually, it is only necessary to provide some switching means for connecting the solenoid winding 53 of the solenoid 50 to some suitable source of power. In the illustrated arrangement, the tachometer generator 59 is used to supply the power for operating the control valve 36 and with this arrangement an additional protective action is obtained as will presently be described. In order to provide means for switching between automatic and manual operation of the pitch control, there is provided a switch 67 comprising a rotary switching member 68 which in the automatic position engages a stationary contact 69 and in the manual position engages a stationary contact 70. The rotary switching member 68 is connected to the rectified output of the tachometer generator while the stationary contacts 69 and 70 are connected to the operating windings 53 and 57 of the sole-

noids 56 and 52, respectively. Thus when the switch 67 is in the position shown in which the switching member 68 engages the contact 69, the rectified output of the tachometer generator is connected to the solenoid 56 so that the control valve 36 is actuated according to the speed of the rotor for the governing action as described above. In this position the solenoid-operated control valve 36 is deenergized so that the hydraulic servo is active. When it is desired to operate the pitch control manually, the switching member 68 of the switch 67 is moved downwardly so that it disengages contact 69 and engages contact 70 whereby the operating winding 51 of the solenoid 52 is connected to the rectified output of the tachometer generator. An adjustable rheostat 72 is shunted across the operating winding 51 and this is adjusted so that when the rotor speed is at the minimum safe value, the current flowing in winding 51 is just sufficient to maintain the valve element 48 of the control valve 36 in the lower position in which the servomotor is inactive. However, if for some reason the pilot inadvertently increases the pitch of the rotor blades too far so that the speed of the rotor falls below the minimum safe value, the force of biasing spring 49 of the control valve 36 exceeds the opposing force of the solenoid 52 and the valve element 48 moves upwardly whereupon the servomotor becomes active. It will be noted that when the switching member 68 is in the lower manual position, the operating winding 57 of the solenoid-operated control valve 23 is disconnected, so that the valve element 25 is moved to the upper position under the influence of the biasing spring 58. Therefore, the upward movement of the valve element 48 of the control valve 36 in response to a falling of the rotor speed below the minimum safe value, causes the pressure line 24 to be connected to the output of the hydraulic pump 29 and since the valve element 25 of the control valve 23 is in the upper position, oil flows from pressure line 24 to line 26, whereupon the actuating shaft 18 of the servomotor 17 immediately moves to the outward position reducing the pitch of the rotor blades to the minimum value. The rotor speed will therefore increase due to the decreased torque required to drive the rotor, but when the rotor speed increases beyond the minimum safe value, the valve element of the control valve 36 will again move downwardly, disabling the hydraulic servo and restoring the manual control to the pilot. Thus it will be seen by energizing the solenoid-operated control valve 36 from the output of the tachometer generator, an additional protective action is obtained which prevents an inadvertent lowering of the rotor speed below the minimum safe value when the pitch-adjusting mechanism is under manual control.

It is believed that the operation of the helicopter rotor speed governing system should now be clear. Assuming that the engine 5 is running and that the rotor is turning, if the pilot desires that the rotor speed be governed automatically, he sets the desired rotor speed by adjusting the control knob 64. He then turns the manually operated hydraulic valve 35 to the "on" position and moves the switch 68 to the upper or automatic position. This action deenergizes the control valve 36 and renders the hydraulic servo system operative. This action also connects the operating winding of the solenoid-operating control valve 23 with the output of the tachometer generator 59. If the speed

of the rotor corresponds to the setting of the speed control knob 64, the valve element 25 of the control valve 23 will be in the center position and the servomotor 17 will remain stationary. If for some reason the speed of the rotor falls below the control point value, the voltage output of the tachometer generator 59 and the current flowing in the energizing circuit of the solenoid system 56 will decrease, whereupon the solenoid plunger 55 and the valve element 25 will move upwardly under the influence of biasing spring 58. This causes servomotor shaft 18 to move outwardly to decrease the rotor pitch, whereupon the rotor speed increases and the valve element 25 is returned to the center position stopping the servomotor. Similarly, if for some reason the rotor speed increases above the said control point value, the voltage output of the tachometer generator 59 and the current supplied to the solenoid 56 increases, moving the solenoid plunger 55 and the valve element 25 downwardly which causes the servomotor shaft 18 to move inwardly to increase the pitch of the rotor blades. When the rotor speed slows down to the set value, valve element 25 again returns to the center position due to the decreased current supplied to the solenoid and the correcting action ceases.

If the pilot desires to increase the lift of the rotor, he opens the throttle 15 which increases the power output of the driving motor 5 and simultaneously decreases the resistance in the solenoid-energizing circuit through the action of the throttle controlled rheostat 65. This increases the current in the solenoid 56 so that the valve element 25 moves downwardly, causing the servomotor 18 to move outwardly in a direction to increase the pitch of the rotor blades thereby anticipating and preventing an upward speed transient which would otherwise be caused by the increased power output of the driving motor 5. Conversely, if the throttle is moved in a closing direction, the reverse action takes place so that the servomotor 17 moves in a direction to decrease the rotor pitch, thereby anticipating and preventing a drop in rotor speed due to the decreased output of the driving motor 5. Thus it will be seen that the inherent sluggish operation of the rotor speed-responsive pitch governor system is greatly reduced by the reduction or elimination of rotor speed transients and the resulting change in kinetic energy of the rotor as described above.

As pointed out above, the combination of the throttle controlled rheostat 65 and the servomotor control rheostat 66 functions to position the servomotor 18 in accordance with the position of the throttle and by properly adjusting the relationship between the rheostats, the throttle controlled servo movement may be selected to reduce or completely eliminate the rotor speed transient or to over-compensate if it is desired to use the kinetic energy of the rotor to obtain momentary additional lift.

As pointed out above, the servomotor controlled rheostat 66 functions additionally to stabilize the governing system by rebalancing the control valve 25 in advance of the rotor speed returning to the set control point value. In the absence of the throttle controlled rheostat 65, this action would introduce a certain amount of regulation into the system, i. e., the governed rotor speed would vary in accordance with the position of the servomotor. However, the action of the throttle controlled rheostat 65 is such that the

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control point speed is reset to the initial value set by the rheostat 63 whereby regulation in the control point speed which would otherwise be caused by the action of the servomotor control rheostat 66 is compensated in a direction to maintain the set rotor speed.

If the pilot desires to manually control the rotor pitch by moving the pitch control lever 12, the switch 67 is moved to the lower or manual position thus switching the output of the tachometer generator 59 from the solenoid-operated servo control valve 23 to the solenoid-operated control valve 36. So long as the rotor speed is maintained above the minimum safe value, the valve element 48 of control valve 36 remains in the lower position in which the hydraulic servomotor 17 is disabled. However, if the pilot should inadvertently increase the pitch of the rotor to a point where the rotor speed falls below the minimum safe value, the valve element 48 moves to the upper position whereupon the servomotor 17 is conditioned for operation as explained above. In the manual position of the control switch 67, the solenoid-operated control valve 23 is de-energized and the valve element 25 is in the upper position so that the servomotor 17 immediately moves the pitch control to the minimum pitch position where it is maintained until the rotor speed returns to a value above the minimum safe value, at which point the valve element 48 of the solenoid-operated control valve 36 returns to the lower position to against disable the hydraulic servo.

If during powered flight the driving motor 5 should fail, the free-wheeling clutch 8 acts to disconnect the driving motor from the rotor so that the rotor will continue to rotate with minimum drag. It will be noted that the governing system under this condition will continue to function as before since both the tachometer generator 59 and the oil pump 29 are driven from the rotor shaft 4. As the rotor starts to slow down upon failure of the driving motor, the governing system will operate automatically to reduce the pitch of the rotor blades so that the rotor speed will be maintained for a safe auto-rotational descent.

If during flight there should for some reason occur a malfunctioning of the governing system, the pilot can, in an emergency, always overpower the governor by simply applying sufficient force to the pitch control lever 12. Application of sufficient force to the pitch control will cause one of the by-pass valves 46 and 47 to open, depending upon the direction of application of the force, by-passing oil between opposite ends of the servo piston so that the servo mechanism is unlocked.

It will be noted that the system is fail-safe. Thus for example if the oil pressure in line 24 should fail for some reason, the spring 40 in the hydraulic servo moves the piston 39 downwardly so as to open the by-pass passageway 38 and thereby free the servomotor for manual control. If the tachometer generator should fail when the control switch 67 is in the automatic position, the control valve 23 will cause the servomotor to move the pitch control mechanism to the minimum pitch position, thereby preventing a dangerous underspeed which might cause the blade 3 to collapse or stall. Likewise, if the tachometer generator should fail when the control switch 67 is in the lower or manual position, control valve 36 will move to the uppermost position, as shown in Fig. 3, under the force of spring 49 to again

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cause the servomotor to move the pitch control mechanism to the minimum pitch position.

Thus it will be apparent from the foregoing that there is provided a helicopter rotor pitch-governing system which, in addition to maintaining a preset rotor speed, permits the rotor lift to be quickly changed in response to a change in throttle position so that precise maneuvering in a vertical direction is possible, the sluggish operation previously encountered with pitch-governing systems being prevented by the elimination of rotor speed transients. Furthermore, the system is fail-safe and in addition gives automatic pitch reduction in case of engine failure. Also automatic rotor pitch reduction is obtained when the pilot is manually controlling the rotor pitch if the pilot inadvertently lowers the rotor speed below the minimum safe value.

While I have shown and described particular embodiments of my invention, it will occur to those skilled in the art that various changes and modifications may be made without departing from my invention, and I therefore aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A governing system for rotary wing aircraft having a lifting rotor and means for varying the pitch and lift of said rotor, said system comprising a servomotor for actuating said pitch-changing means, a first electroresponsive control device for controlling the direction of movement of said servomotor, a second electroresponsive control device for disabling said servomotor, a tachometer generator driven in accordance with the speed of said rotor, and a switching device for selectively connecting said tachometer generator to said first and second electroresponsive control devices.

2. A governing system for a rotary wing aircraft having a lifting rotor and means for varying the pitch and lift of said rotor, said system comprising a servomotor for actuating said pitch-changing means, a first device operable in either direction from a neutral position for controlling the direction of movement of said servomotor in accordance with the position of said control device, said control device having means for biasing it to the direction causing said servomotor to move said pitch-changing means towards the minimum pitch position, and electroresponsive actuating means for moving said control device in the opposite direction to cause said servomotor to move said pitch-changing means towards the maximum pitch position, a second control device operable to either of two positions for rendering said servomotor active or inactive, said second control device having means for biasing it to the position in which said servomotor is active and electroresponsive actuating means for moving said second control device to the other position in which said servomotor is inactive when the current supplied thereto exceeds a predetermined critical value, means for producing a voltage variable in accordance with the speed of said rotor, means comprising a selector switch having manual and automatic positions for selectively connecting said voltage producing means to the electroresponsive actuating means of said first and second control devices, whereby said first control device controls said servomotor to maintain constant speed of said rotor when said selector switch is in the automatic position, and said second control device maintains said servomotor inactive in the

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manual position unless the output of said voltage producing means and the current in the electro-responsive actuating means of said second control device falls below said critical value corresponding to a minimum safe rotor speed in which case said second control device moves to the position in which said servomotor becomes active and said first device causes said servomotor to move said pitch-changing means to the minimum pitch position.

3. A rotor speed governing system for a rotary wing aircraft having a variable pitch rotor, pitch-changing means for varying the pitch and lift of said rotor, a power means for driving said rotor, and a throttle for varying the power output of said power means, said governing system comprising a servomotor for actuating said pitch-changing means, a control device for controlling the direction of movement of said servomotor, means responsive to deviations in speed of said rotor from a control point speed for actuating said control device to cause movement of said servomotor and said rotor pitch-changing means in a direction to correct for said speed deviation, means responsive to movements of said throttle for causing actuation of said control device and a resulting movement of said servomotor and pitch-changing means in a direction to oppose a transient change in rotor speed which would otherwise occur due to the change in power output of said power means in response to movements of said throttle, and means responsive to movements of said servomotor and pitch-changing means for causing the actuation of said control device and the movements of said servomotor to be limited in accordance with the amounts of movement of said throttle.

4. A rotor speed governing system for a rotary wing aircraft having a variable pitch rotor, pitch-changing means for varying the pitch and lift of said rotor, a power means for driving said rotor, and a throttle for varying the power output of said power means, said governing system comprising a servomotor for actuating said pitch-changing means, a control device for controlling the direction of movement of said servomotor, means responsive to deviations in speed of said rotor from a reference speed for actuating said control device to cause movement of said servomotor and said pitch-changing means in directions to correct for said speed deviations, means responsive to the positions of said pitch-changing means to change said reference speed of said speed responsive means in the direction of speed deviation to stabilize said governing system, and

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means responsive to the positions of said throttle to change said reference speed of said speed responsive means to compensate for changes of reference speed which occur due to the operation of said means responsive to positions of said pitch-changing means as said throttle is adjusted to change the power output of said power means.

5. A governing system for a rotary wing aircraft having a variable pitch lifting rotor, a power plant for driving said rotor including a throttle for controlling the power output of said power plant, said system comprising a servomotor for varying the pitch and lift of said rotor, an electric current responsive control device operable to change the position of said servo, an electrical generator arranged to be driven by said rotor for the generation of an electric control current of a magnitude proportional to the speed of said rotor for the actuation of said control device to maintain a predetermined rotor speed by regulation of the pitch of said rotor, a follow-up control for changing the pitch of said rotor in accordance with a change in the position of said throttle comprising first and second rheostats connected in series between said generator and said current responsive control device, said first rheostat being adjustable in accordance with the position of said throttle and said second rheostat being adjustable in accordance with the position of said servomotor.

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Disclaimer

2,517,150.—*Donald R. Webb*, Schenectady, N. Y. GOVERNOR. Patent dated Aug. 1, 1950. Disclaimer filed Nov. 2, 1951, by the assignee, *General Electric Company*.

Hereby enters this disclaimer to claims 3 and 4 of said patent.
(*Official Gazette February 12, 1952.*)