March 17, 1959 F. R. PRELI ET AL 2,878,426

SIGNAL LIMITING MEANS FOR SYNCHRONIZER

Filed Dec. 27, 1955

5 Sheets-Sheet 1

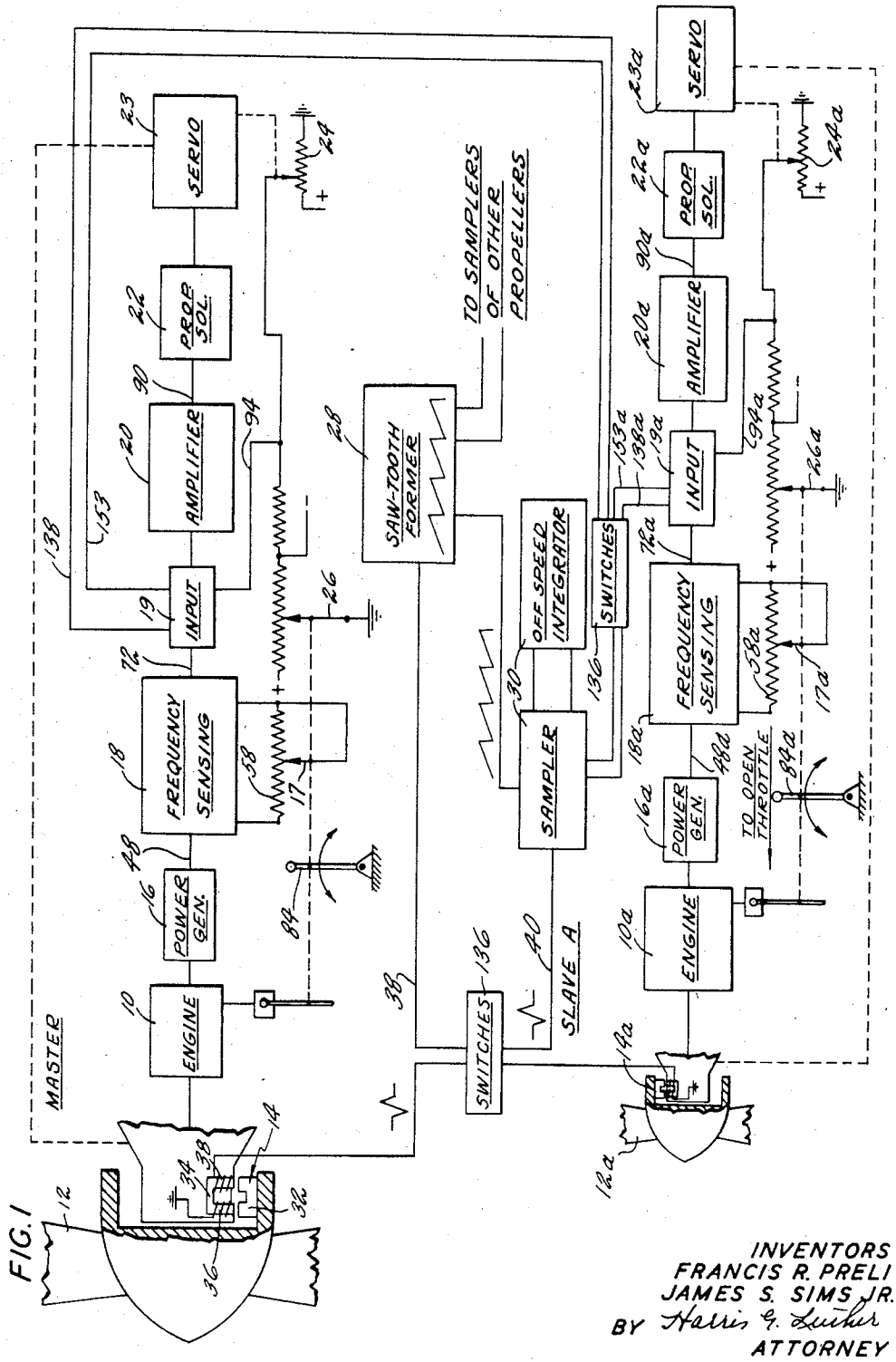


FIG. 1

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5 Sheets-Sheet 2

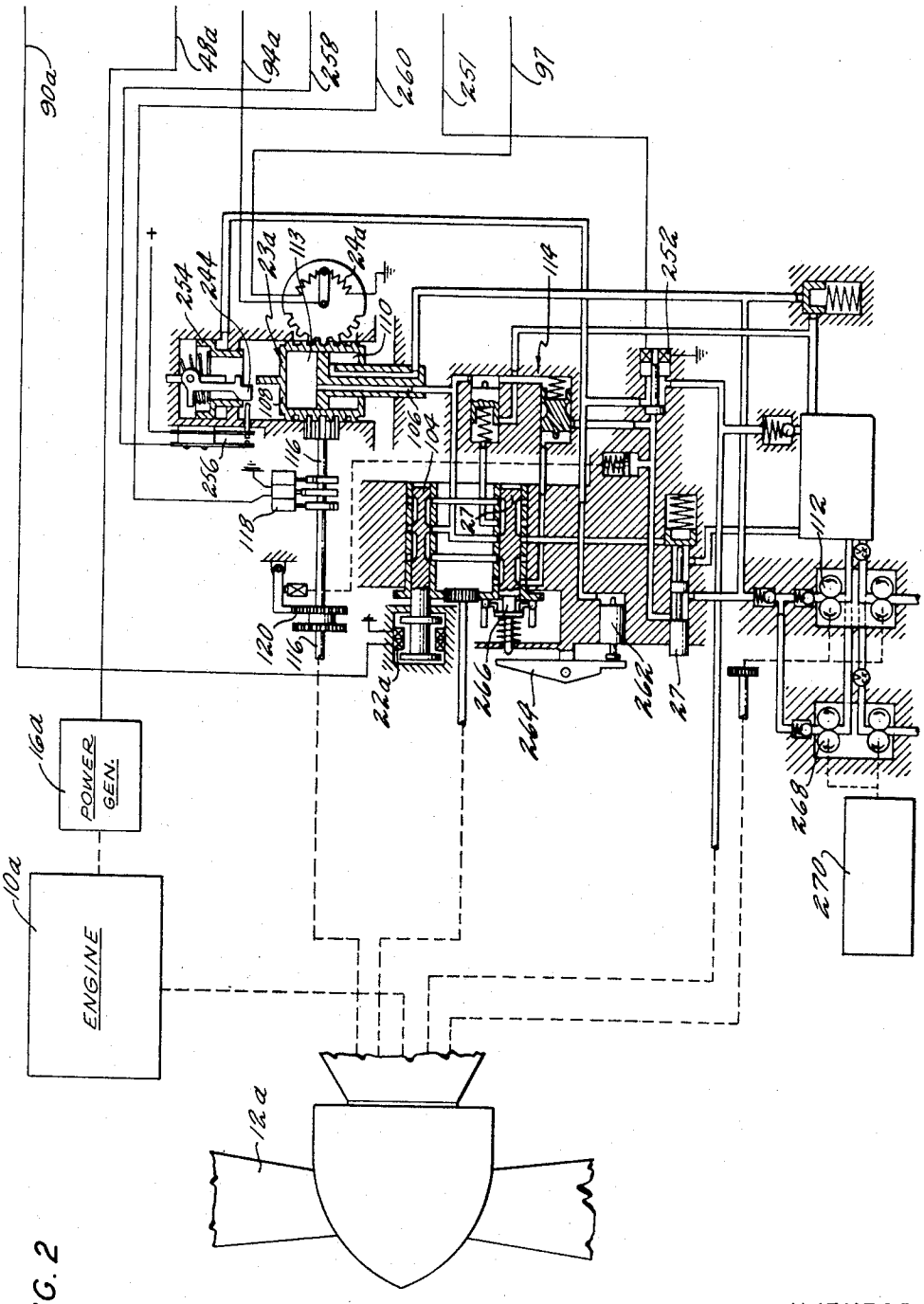


FIG. 2

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SIGNAL LIMITING MEANS FOR SYNCHRONIZER

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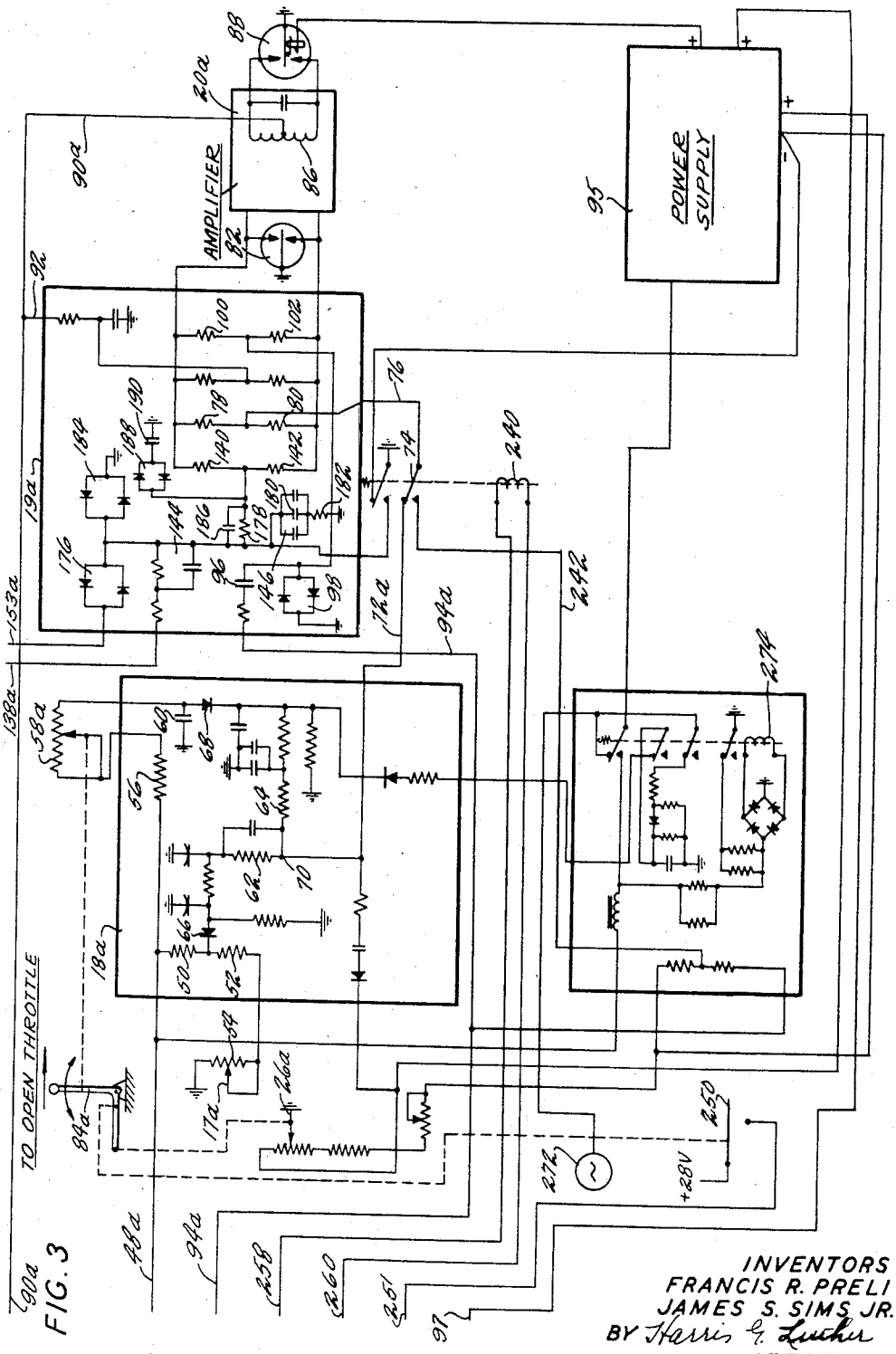


FIG. 3

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SIGNAL LIMITING MEANS FOR SYNCHRONIZER

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5 Sheets-Sheet 4

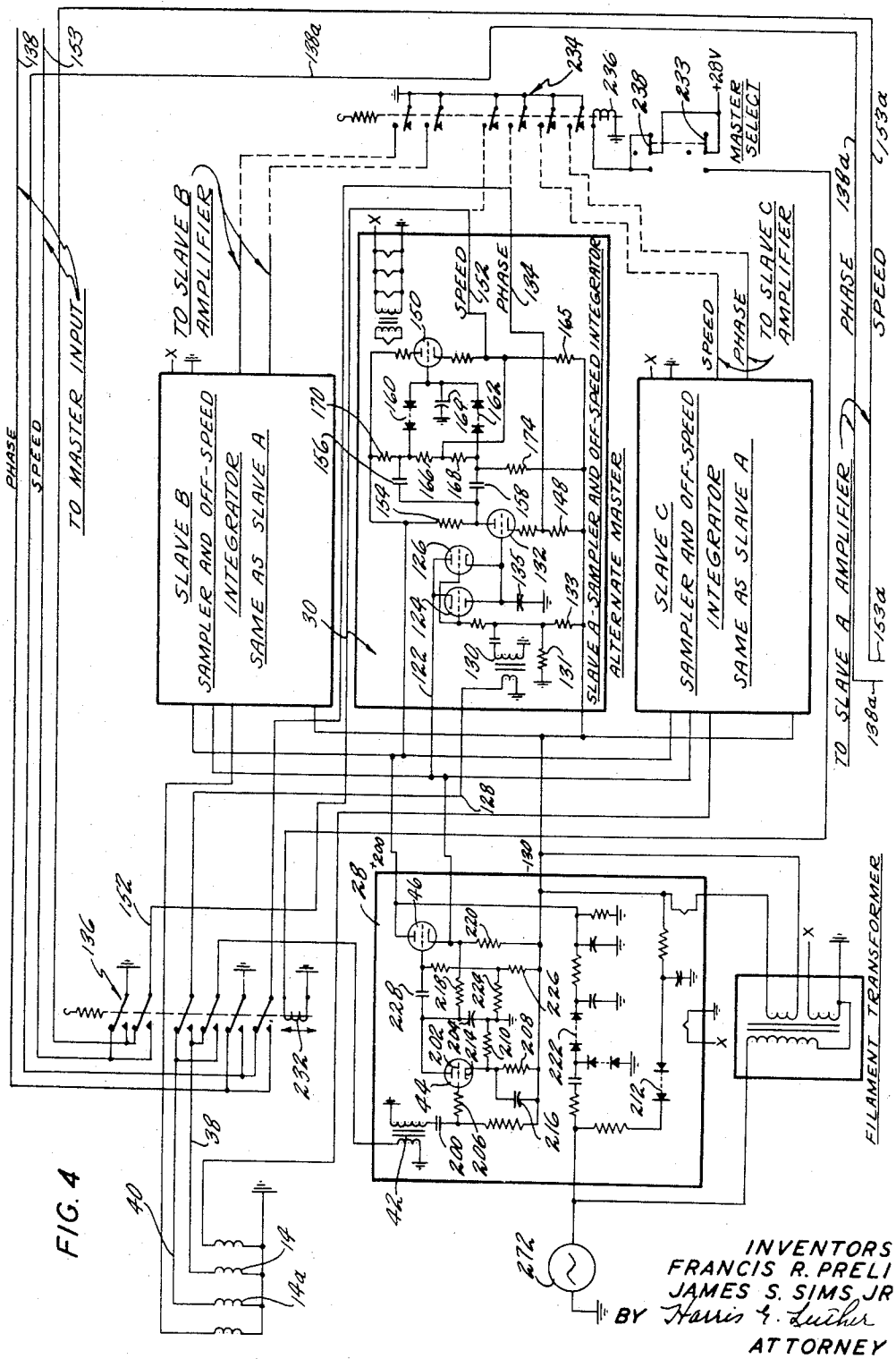


FIG. 4

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SIGNAL LIMITING MEANS FOR SYNCHRONIZER

Filed Dec. 27, 1955 5 Sheets-Sheet 5

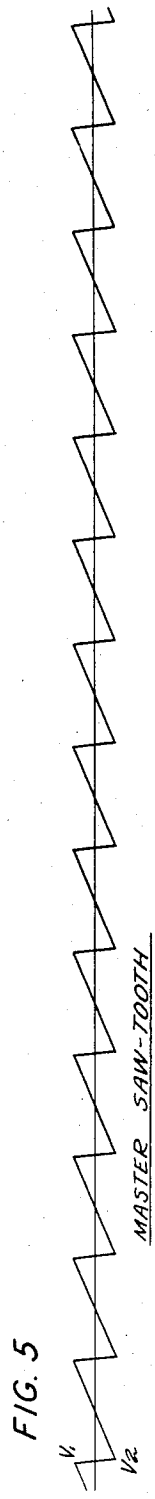


FIG. 5



FIG. 6

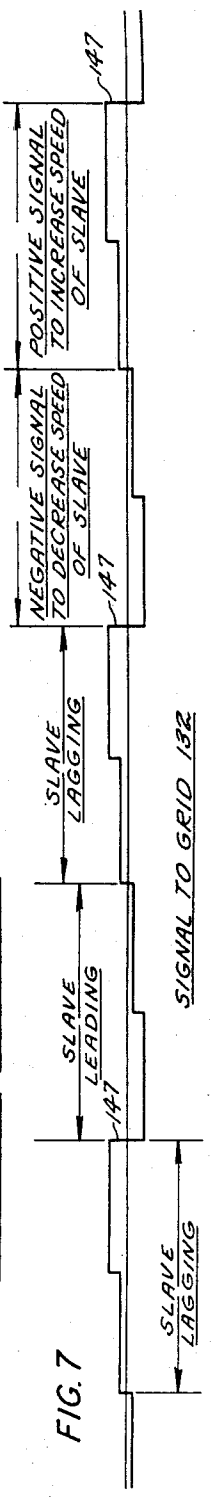


FIG. 7

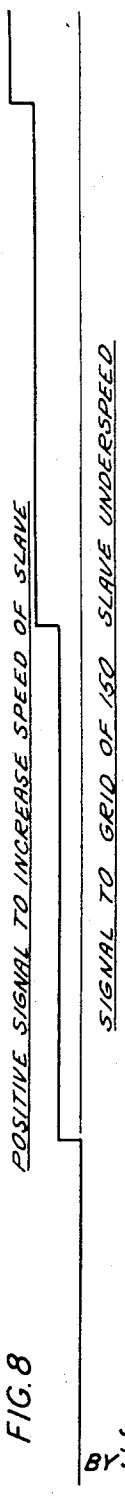


FIG. 8

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United States Patent Office 2,878,426 Patented Mar. 17, 1959

2,878,426

SIGNAL LIMITING MEANS FOR SYNCHRONIZER

Francis R. Preli, East Hartford, and James S. Sims, Jr., Granby, Conn., assignors to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

Application December 27, 1955, Serial No. 555,594

11 Claims. (Cl. 317—6)

This invention relates to synchronizing mechanism for two or more devices and particularly to mechanism for synchronizing the rotation of propulsion devices such as aircraft propellers.

An object of this invention is an improved mechanism which compares a master signal from one device with a slave signal from a slave device and produces an electric signal which may be utilized to control the speed and phase of the slave with respect to the master, including means limiting said electric signal to prevent excessive speed changes of said slave.

A further object of this invention is a control having phase responsive mechanism and having an off-speed integrator for modifying the phase signal to bring two devices back into synchronism and phase and a limiter preventing the passage of a signal greater than a preselected value to the control mechanism.

Further and other objects will be apparent from the following specification and the attached drawings in which:

Fig. 1 is a block diagram showing one master unit and one slave unit with provision for controlling other slave units by the master.

Fig. 2 is a schematic drawing showing a portion of the hydro-mechanical section of one of the propeller controls.

Fig. 3 is a portion of the electric circuit controlling the hydro-mechanical portion of Fig. 2.

Fig. 4 is a schematic wiring of the synchronizer and phasing portion of the electronic control showing how the output of one of the samplers is connected to the electric portion of the one control shown in Fig. 3.

Fig. 5 is a diagram showing the saw-tooth voltage wave from the wave former.

Fig. 6 is a diagram showing the voltage curve of the pulse from the pulse generators.

Fig. 7 is a diagram showing the voltage curve produced by the sampler and the type of signal fed by the phaser to the amplifier.

Fig. 8 is a diagram showing the signal produced by the off-speed integrator and the type of signal fed by the off-speed integrator to the amplifier.

In the operation of multi-engine aircraft it has been found desirable both from a vibration and a noise standpoint to not only synchronize the several engine-driven propellers but to also maintain a selected phase relation between the propellers. Mechanism responsive to speed alone is not capable of maintaining the required phase relation even when such mechanism is capable of maintaining fairly close speed synchronization.

Applicant has invented an improved device which may be used to control the speed of each propeller independently with the synchronizing mechanism disconnected or may be able to synchronize the several propellers and maintain a selected phase relation between them within comparatively small limits with the synchronizing mechanism connected. The propeller which has been chosen to explain the synchronizer mechanism is a propeller similar to that shown in Longfellow Patent No. 2,652,122.

In this propeller type, a proportional solenoid energized by speed responsive mechanism, which may be of the type described in Patent No. 2,579,723, positions a valve controlling a servomotor mounted on a non-rotating support, which servomotor acting through a gear train positions a follow-up distributor valve on the rotating propeller hub to control the flow of hydraulic fluid to a hydraulic motor on the porpeller to position the propeller blades in accordance with the position of the servomotor. The solenoid of the master and slave may be supplied with an exciting voltage from a respective frequency responsive speed selecting circuit and if phasing is desired, the slave may also be supplied with an exciting voltage from a speed and phase comparing mechanism comparing the speed and phase of the controlled propeller with the speed and phase of a master and providing an exciting voltage upon any variations of the slave speed and phase from that of the master. These latter speed and phase signals are, within limits, utilized to modify and override the speed signals from the frequency responsive circuit.

As shown in Fig. 1, a master engine **10** drives a propeller **12**. A single phase alternating current power generator **16** is driven by the engine **10** and its output is led to a frequency sensing device **18**, which may be similar to the frequency sensing mechanism shown in application Ser. No. 261,020 of Thomas P. Farkas, filed December 11, 1951, now Patent No. 2,772,378, in which the impedance of a circuit is designed to maintain the voltage drop in a portion of the circuit at a substantially constant value selected by speed selector **17** irrespective of frequency changes. This selected constant voltage is compared with the normal generator voltage, which varies with speed, to obtain a resultant signal or speed error signal, showing speed deviation from the selected speed. The speed deviation or speed error signal is fed into an input box **19** and then into an amplifier **20** and after amplification is led to the proportional solenoid **22** controlling the servomechanism to change the propeller pitch to return the propeller-engine speed to the speed manually selected by selector **17** in the frequency sensing device **18**.

The slave propellers have identically the same mechanism as that described above for the master propeller and the path has been indicated in Fig. 1 for one slave by the same numerals as the master with the suffix "*a*." Any desired number of slave propellers may be controlled from a single master. Fig. 4 shows how three slaves may be controlled. Only one slave is shown in Figs. 1, 2, and 3 for purposes of simplicity, but it is believed to be obvious how others may be added. The slave propeller as shown in Fig. 1 is, however, in addition to the mechanism shown for the master, provided with a control device or synchronizer which will compare the speed and phase of the slave propeller with that of the master and supply a speed or phase error signal to the input mechanism **19***a* to bring the slave propeller speed and phase into synchronism with that of the master. Switches **136**, as explained in more detail hereinafter, may be provided to select either propeller shown in Fig. 1 as the master, making the other propeller the slave.

The speed control mechanism is effective over a control range of pitch angles, the lower limit of which is determined by a low pitch stop. Mechanism is provided for removing the stop under certain conditions at which time the speed control mechanism is disabled and control of the propeller is obtained through individual Beta control mechanism connected with the respective throttle control lever. The Beta control mechanism comprises a device for comparing the blade angle setting indicated by the servo potentiometer **24** with a blade angle selected by the Beta control **26** and feeding the resultant signal to the same input mechanism **19** which

received the signal from the frequency sensing device of the speed control. The Beta control is used in starting and in reverse pitch to give a blade angle in accordance with the position of the respective throttle control lever. This Beta mechanism is explained in more detail hereinafter and in Farkas application Ser. No. 314,593, filed October 14, 1952, now Patent No. 2,840,169.

Feathering may be accomplished by mechanically biasing plunger **27**, Fig. 2, of the hydraulic mechanism of the propeller, to hydraulically move servo **23***a* thus overcoming the control of the servo **23***a* by the proportional solenoid to change the propeller pitch and feather the propeller.

Taking up the speed control in detail, the master and slave have identical independent speed control mechanisms but they will be explained for the slave propeller only because of the more detailed drawings thereof. The A. C. output of the power generator **16***a*, Fig. 2, is fed in on line **48***a* to the portion of the electronic governor shown in Fig. 3 and into a bridge having resistor **50** forming one leg of the bridge, resistors **52** and **54** forming another leg of the bridge, resistors **56** and **58***a* forming a third leg of the bridge and condenser **60** forming the fourth leg of the bridge. The A. C. voltage at the midpoint of the two sides of the bridge is passed through rectifiers **66** and **68** respectively and their associated filter circuit to change the A. C. voltages to D. C., and the resulting D. C. voltages are compared at the junction **70** of resistors **62** and **64**. The convention used in this application is that the arrows in the rectifiers indicate the flow of current from plus to minus as distinct from electron flow. Any variation in speed of the power generator **16***a* from that selected by the setting of the variable resistance **58***a* will be indicated as a D. C. voltage at the junction **70** of resistors **62** and **64**, the polarity and magnitude of the voltage being an indication of the direction and extent of the speed error. The speed error signal is led through line **72***a*, switch **74**, and line **76** to the midpoint between resistors **78** and **80** in input box **19***a* and through to the vibrator **82** and to the amplifier indicated generally at **20***a*. As indicated in Fig. 1, the speed setting resistor **58***a* is set by movement of the throttle control **84***a* connected with the selector arm **17***a* so that in order to change the speed setting of the propeller it is necessary to move the engine throttle. The direct current signal fed from input box **19***a* to the vibrator **82** is chopped into a square wave signal and amplified in amplifier **20***a* in a well known manner and after passing through a transformer **86** is again chopped by vibrator **88** operating in synchronism with vibrator **82** to provide a direct current output on line **90***a* to the proportional solenoid **22***a*, a portion of which current is led back through line **92** to form a negative feedback for the amplifier **20***a*. The servo potentiometer **24***a* shown in Fig. 1 is connected to a positive voltage in the power supply **95** by line **97** and the wiper of potentiometer **24***a* is connected by a line **94***a* and a condenser **96** and limiting mechanism **98** to a midpoint between resistors **100** and **102** to provide a variable sensitivity circuit forming the subject matter of patent application Ser. No. 517,544 filed June 23, 1955 by C. B. Brahm to which reference may be made for further details as it is believed that a further description of this particular circuit is not necessary for a complete understanding of the present invention. As shown schematically in Fig. 2, proportional solenoid **22***a* controls pilot valve **104** to control the flow of fluid to one side of servo **23***a*. Servo **23***a* comprises a fixed piston **106** and a movable cylinder **108** having oil at a constant pressure introduced to one side **110** from the main pumps **112** and having oil at greater or lesser pressure introduced to the opposite side **113** by the pilot valve **104**. Mechanism indicated generally at **114** is used to supply pressure at a predetermined amount above and a predetermined amount below the pressure existing in the side **110** of the servo. This mechanism is explained in more detail in patent application Ser. No. 437,326 filed by Harry M. St. John, Jr. on June 17, 1954 for Pitch Control Servo System for an Aeronautic Propeller. Further detailed description of the pressure supply is not believed necessary for a complete understanding of the present invention. Movable cylinder **108** serves to actuate the servo potentiometer **24***a* to provide the variable sensitivity circuit when under speed control. As explained in more detail hereinafter, the same potentiometer is used to provide a blade indicating position when under Beta control. Cylinder **108** also actuates a shaft **116** having a set of blade angle switches **118** connected therewith. A low pitch lock ratchet **120** similar to pitch lock unit 268 in the Longfellow patent is also connected with shaft **116** which continues and drives the gear mechanism shown in more detail in the Longfellow patent and is the equivalent of shaft 168 of that patent. It should be sufficient for this application to state that shaft **116** through the gear mechanism actuates a distributor valve, not shown, in the propeller hub which has a follow-up mechanism connected thereto and serves in a well known manner to position the propeller pitch in accordance with the position of the servo cylinder **108** so that each propeller pitch position corresponds to a predetermined position of the servo cylinder **108**.

From the above detailed description it will be apparent that any variation in the speed of the power generator **16***a* and the propeller **12***a* which is geared thereto, from a speed selected by the governor setting mechanism **58***a* will result in an electrical signal at the junction between resistors **78** and **80** which will be amplified and fed to the proportional solenoid to actuate the servo mechanism **23***a* and change the propeller pitch to change the power generator speed and destroy the speed error signal which actuated the proportional solenoid, thus allowing the proportional solenoid to return to a neutral or on-speed position. This same action takes place independently in each of the propellers when they are connected for individual control, the speed of each propeller being controlled by its individual throttle lever **84** and the respective speed selector **58** connected thereto.

Phasing and synchronizing

The pulse generators and their associated mechanism shown and described but not claimed herein are claimed in an application of Best for Synchronizer (HS–311), filed on even date herewith.

Taking up the phasing and synchro-mechanism specifically, the pulse generator **14** of the master propeller **12** feeds a pulse signal into a saw-tooth former **28** which will transform the comparatively sharp pulse into a saw-tooth wave having a repetition rate in synchronism with the rotation of the propeller **12**. In the now preferred construction, the pulse occurs once per propeller revolution, so that the saw-tooth occurs once per propeller revolution. The pulse from the pulse generator **14***a* of the slave propeller **12***a* is led to a sampler **30** to which the saw-tooth wave formed by the saw-tooth former **28** of the master is also led. By commutating the saw-tooth wave of the master engine with the pulse from the slave engine, a signal is obtained indicating the direction and extent of out-of-phase position of the slave with respect to the master. This out-of-phase signal is fed to the input box **19***a* and thence to the amplifier **20***a* and the proportional solenoid **22***a* and the servo mechanism **23***a* which being connected with the propeller **12***a* will change the propeller pitch in such a direction as to bring the slave propeller into phase with the master at which time the error signals will be cancelled and become zero.

In the event that the slave propeller is running at a speed different from the master such that the repetition rate of the slave pulse is continuously different from that of the master pulse or saw-tooth wave, provision is made for accumulating the voltage impulses resulting from

the consecutive slave pulses by sampling opposite sides of the steep portion of the saw-tooth wave to thus provide a speed difference signal which is also fed to the input box **19***a* to provide an additional signal to the proportional solenoid **22***a* to further change the propeller pitch to correct for this speed difference and bring the slave and master into synchronism.

These speed and phase signals within limits modify and override the speed signal from the frequency sensing mechanism so as to maintain an in-phase and synchronous condition with the master although the frequency sensing mechanism of the slave may be calling for a different speed from that of the master within a predetermined limit.

The pulse signals from which the saw-tooth wave is formed on the master engine and the pulse signal which is used together with the slave engine for commutating the saw-tooth wave are produced by pulse generators shown generally at **14** and **14***a*. The pulse generator (see Fig. 1) comprises a permanent magnet **32** mounted to rotate with the propeller and to pass in close proximity to a horseshoe-shaped core **34** held against rotation by the engine **10**. Core **34** carries a pair of coils **36** and **38**, connected in series so as to add the voltages induced in the coils by the passage of the permanent magnet **32** past the coils. One free end of the coils is grounded and in the master the other free end of the coil is connected by wire **38** to the saw-tooth former **28**. In the slave the other free end of the coil is connected by line **40** to the sampler **30**. As shown in Fig. 4 line **38** from the master pulse generator leads to a saw-tooth former **28** having a transformer **42** for stepping-up the voltage of the pulse. The pulses are then led through electronic circuits including a tube **44** and a tube **46**, similar to the tubes **55** and **50** of the Offner Patent No. 2,517,703, where they are transformed into a linear saw-tooth wave **14**. The saw-tooth wave is formed in a manner similar to that explained in the Offner patent so that the following brief explanation of the saw-tooth former structure here is believed all that will be necessary.

The pulse developed by the master engine is coupled via condenser **200** to the signal grid **202** of the tube **44** which, with its associated circuit components, converts the pulses into waves having the desired saw-tooth form.

Briefly, condenser **204** is charged to a negative value close to the negative cathode potential of tube **44** when the positive portion of the pulse applied to condenser **200** causes the bias on the grid **202** applied through resistor **206** to be greater than cut off. Resistors **208** and **210**, forming a voltage divider from the negative voltage, say 130 volts, of rectifier **212** place a negative voltage on the cathode **214** which is slightly positive with respect to the grid **202** so that the tube **44** is normally nonconducting. Capacitor **216** serves as a by-pass to prevent any rapid changes in cathode current appearing as a bias on the tube. Condenser **204** is discharged through resistors **218** and tube **46**.

Resistor **220** is a cathode resistor of tube **46** which is a cathode follower type of tube having a plate voltage, of say plus 200 volts, supplied by the rectifier **222**. Resistors **224** and **226** establish the bias of the grid of the tube **46** so that the average current through tube **46** is constant and hence the voltage appearing at the junction of resistors **218** and **220** has some average constant value between minus 130 and plus 200, say around zero volts. Hence condenser **204** will charge to some negative value of say 110 volts when tube **44** conducts and will be slowly discharged through resistors **218** and tube **46** to a voltage a fixed amount less than the voltage at their junction, say 70 volts less. The voltage across condenser **204** is shown by the curve of Fig. 5 and is seen to be of the desired saw-tooth form. The current pulse through tube **44** causes a voltage across condenser **204** to drop from V_1 of say minus 30 volts to V_2 of say minus 110 volts. If the voltage at V_2 is some fixed value, such as minus 110 volts, the voltage of V_2 minus V_1 will not depend on the frequency. The reason for this is that the alternating component of the voltage on condenser **204** is applied to the grid of tube **46** through condenser **228**. The average grid bias with respect to ground on tube **46** is held constant through resistors **224** and **226**. Tube **46** acting as a cathode follower, the alternating voltage existing across its cathode resistor is only slightly less than across condenser **204**. Therefore, the current flowing through resistor **218** will be small. If the average voltage across condenser **204** should tend to increase, that is, have a higher numerical negative value due to increased pulse frequency, there will be a large increase in the current through resistor **218** since the average voltage across cathode resistor **220** is constant. This increased current through resistor **218** will quickly charge condenser **204** until the average voltage returns practically to its original value. This will then place the voltage at V_1 at its former value so that V_1 minus V_2 is again the same voltage and the amplitude of the wave remains substantially constant.

For any fixed frequency, condenser **204** will discharge at a constant rate due to a constant difference between the cathode and grid voltages of the cathode follower tube **46**. Discharging at this constant rate will provide a linear saw-tooth wave.

The linear saw-tooth voltage from the saw-tooth former **28** is led on line **122** to a sampler **30** having a circuit comprising tubes **124** and **126** and having the cathode of tube **124** and the plate of tube **126** connected to the saw-tooth input by line **122**. The pulse from the pulse generator **14***a* of the slave engine is fed in on line **128** to a transformer **130** and thence to the grid of both tubes **124** and **126**. A negative bias is normally maintained on both grids by the resistors **131** and **133** forming a voltage divider and connected into a minus 130 volt line. The positive portion of the pulse from generator **14***a* will cause one of the tubes **124**, **126** to conduct and charge condenser **135** and thus sample the saw-tooth voltage and place a resultant signal on the grid of tube **132** which will indicate the direction and extent of out-of-phase of the master with respect to the slave.

The fixed grid bias on the grid of tubes **124** and **126** is so adjusted that no anode current can flow through either tube, except when the positive pulse is applied to the grids from the slave pulse generator.

To explain the action of the sampling device, assume that condenser **135** has been charged so as to apply a positive voltage to the plate of tube **124**, the cathode of **126**, and the grid of tube **132**. If at the time the positive pulse is applied to the grids of tubes **124** and **126**, the saw-tooth wave from the master applied to tubes **124** and **126** is more positive than the charge on the condenser, then tube **126** will conduct, charging condenser **135** to a more positive value. While if at that instant the saw-tooth wave from the master were more negative or less positive than the condenser **135**, then tube **124** will conduct and reduce the charge on the condenser. Thus a phase difference voltage wave will be developed across an energy storage device such as condenser **135** as shown by the curve of Fig. 7. It is evident from Fig. 7 that the phase difference voltage at condenser **135** corresponds in polarity and magnitude to that of the saw-tooth wave at each sampling instant and is constant between sampling cycles and further is proportional to the phase difference at the start of each cycle. If the frequencies of the pulses remain the same, and their phase relationship remains unchanged, condenser **135** will remain at that charged potential. Should the phase relationship change, the voltage across condenser **135** would assume a new value proportional to the phase relationship between the saw-tooth and the slave pulse as shown in Fig. 7. No significant current will flow from condenser **135** to grid of tube **132**.

Further explanation of this sampling mechanism is

believed unnecessary here because this sampling mechanism is substantially the same as that shown in Offner Patent No. 2,517,703 mentioned above to which reference may be made for a more detailed description. Tube **132** being a cathode follower type will, from the voltage at the upper end of resistor **148**, give an indication in line **134** of the out-of-phase condition. The cathode resistor **148** and the unnumbered cathode resistor, and the plate resistor **154** for the tube **132** are so chosen that the voltage at the upper end of resistor **148** will vary in polarity in accordance with that of the saw-tooth wave at each sampling instant. As shown in Fig. 4, this out-of-phase indication is led through a master selector relay switch indicated generally at **136** to the output line **138***a* which as shown in Fig. 3, is connected to a midpoint between resistors **140** and **142** and also connected with lead network **144** and lag network **146**. With the voltage existing at the upper end of resistor **148**, fed to the proportional solenoid **22***a* so as to change the phase relation of the slave propeller to the master propeller in the proper sense, the phase change will reduce the voltage at the upper end of resistance **148** to zero, indicating on-phase, thus synchrophasing would be accomplished.

Actuation of master selector relay **232**, Fig. 4, and switches **136** which are controlled by switch **233** will ground out lines **138***a* and **153***a* leading to input box **19***a* and connect the sampler **30** and off-speed integrator with lines **138** and **153** leading to the input box **19** of the master, and at the same time unground lines **138** and **153**. The impulse generator **14** is simultaneously disconnected from the saw-tooth former **28** and connected with the sampler **30** and the pulse generator **14***a* is disconnected from sample **30** and connected with the saw-tooth former **28**, so that the engine and propeller which were slave A are now the master, and the master will become a slave.

Switches indicated generally at **234** controlled by relay **236** are energized by actuation of the switch **238** to either the right- or left-hand position shown in Fig. 4 to unground on the sampler circuits and in effect connect in the synchronizer mechanism. When the switch **238** is on the midpoint, the relay **236** is de-energized and the switches are all actuated to ground out the several samplers and off-speed integrators and put the propellers all back under control by their individual governors alone. The value of resistors **140** and **142** is much higher than the value of resistors **78** and **80** through which resistors the off-phase and the slave speed error signals are combined so that grounding of the synchronizer circuits and resistors will not materially affect the operation of the speed control acting through resistors **78** and **80**.

Off speed integrator

If the relative rotation of the propellers were to change by more than 180°, an erroneous signal would be obtained, indicating that the propellers were off-phase in the opposite direction from that in which the correction was being made. In order to solve this problem, an off-speed integrator is supplied which will count the number of revolutions of off-phase which exists and produce a signal proportional to that number to be applied to the amplifier and thus overcome speed setting misalignment. The off-speed integrator utilizes a pulse **147**, Fig. 7, produced by the rapid change in the saw-tooth wave in the plate circuit of tube **132** and energizes cathode follower tube **150** to produce an off-speed signal in line **152**. The signal in line **152** is fed through a selector relay **136** to line **153***a* and eventually combined with the off-phase signal and fed to the amplifier **20***a*.

The operation of the off-speed integrator is best explained by assuming that a constantly increasing phase error exists between the slave and the master due to underspeed of the slave. The voltage across resistance **148** will then be saw-tooth in form, really composed of small steps whose frequency depends on the speed difference between the slave and the master, Fig. 7. At the end of each revolution of relative phase there will be an abrupt change **147** from positive to negative in the voltage across resistance **148**. The phase circuit would make no distinction between plus 180 and plus 540°. However, the abrupt change in voltage will indicate the change every time it occurs. If a condenser is charged every time the abrupt change occurs and the voltage did not materially leak off the condenser between changes, the voltage across the condenser would indicate the number of times and the direction the relative phase had gone through 180°. If the phase were changing in one direction, i. e., the slave underspeeding, the charge on this condenser should continually be going positive to effect an increase in speed, and if the phase were changing in the other direction, i. e., the slave overspeeding, the voltage across this condenser should continually be going negative to decrease the speed. This voltage could then be added to the off-phase signal, and the effective range of synchrophasing could thus be extended.

In practice, it is found that the abrupt change occurring across resistor **148** is of the wrong sense to charge a condenser so that the off-speed and off-phase signal will add to accomplish the desired result.

The phase can, however, be reversed by utilizing the plate circuit of the cathode follower tube **132** by placing a resistance **154** in that plate circuit. For an underspeed of the slave the voltage change which would be positive across resistance **154** caused by the large negative going pulse to the central grid of tube **132** induced by the abrupt change in saw-tooth voltage, is coupled through condensers **156** and **158** to rectifiers **160** and **162**. If the voltage change across **154** is toward plus, i. e., slave underspeed, rectifier **162** will conduct and charge condenser **164**, to some higher (more positive) value than it had previously achieved. This increased (positive) potential will be applied to the grid of tube **150**. Each pulse charging condenser **164** is additive until a maximum is reached, and thus each additional charge drives the grid of tube **150** more positive to increase the current in cathode resistor **165** and increase the voltage in line **152**. The potential at the cathode of tube **150** will, due to the cathode follower action, be almost that existing across the condenser **164**. This positive cathode voltage is applied to the junction between resistors **166** and **168** which connects the junction between condenser **156** and rectifier **160** with the junction between condenser **158** and rectifier **162** thus tending to maintain the charge on condenser **164**. These resistors together with resistor **170** and resistor **174** serve to bias the rectifiers **160** and **162** so that no conduction will occur in tube **150** except when a material change in voltage occurs at the plate of tube **132**. The sizes of the condensers **156** and **158** are such, and the contact potentials of rectifiers **160**, **162** are such, that an abrupt and material change in voltage is required to make the rectifiers conduct. Thus a slow change in phase between plus 180 and minus 180 degrees will not charge condenser **164**, but when the phase circuit goes through the 180° mark, an abrupt and material change will occur and charge condenser **164** to some new value.

The action for negative change, i. e., slave overspeed, at the plate of tube **132** is exactly the same except that all polarities of signals are reversed and rectifier **160** conducts, biasing the grid of tube **150** to reduce the current flow and produce a more negative voltage in line **152** which will assist the voltage in line **134** in restoring speed and phase coincidence.

The off-phase signal in lines **134**—**138***a* and the off-speed signal in lines **152**—**153***a* existing at the cathodes of tubes **132** and **150**, respectively, are combined in the input box **19***a* and fed to the vibrator **82** and to the amplifier **20***a*. The output of line **153***a*, after passing out of the limiter **176**, Fig. 3, is connected to line **138***a* where it joins resistor **178** leading to the junction between resistors **140** and **142** connected to the vibrator **82**. Con-

densers 180 and resistor 182 of the lag network 146 serve as an integrator to obtain high static sensitivity by blocking the flow of D. C. signals to ground while stable control is still possible because of reduced dynamic sensitivity. This reduced dynamic sensitivity is necessary only when a large speed difference exists between the slave and master engines. During this condition, the voltage is changing rapidly and assumes a condition which resembles noise. This is because the off-speed integral soon reaches the limit of its capabilities which are determined by the voltages selected for off-speed integrator tube 150 and by the contact potential of the rectifiers 184. The rapidly changing off-phase voltage exists as a saw-tooth wave form, see Fig. 7. The condenser of the lead network 144 and condenser 186 will pass these rapidly changing signals which become a series of pulses. The rectifiers 188 and condenser 190 act as limiters, preventing these pulses from reaching the electronic governor in any value over the contact potential of the rectifiers 188 plus whatever charge there may be on the condenser 190. The action of this limiter is different from that of a condenser alone, due to the contact potential of the rectifier 188. A definite magnitude of voltage is required before the limiting will occur. Any steady state voltage existing across the limiter will charge the condenser 190 so that dynamic limiting will occur about this condenser voltage.

It is desirable to limit the effect of the off-speed integrator so that in the event the master should fail, the off-speed integrator or synchronizer can carry the slave engine down below the slave governor setting only a small percentage, preferably of the order of 3%, of the speed setting of the slave engine governor and will not run the slave engine speed down to zero. This limiting of the amount of speed change of which the synchronizer circuit as a whole is capable may be achieved by selecting the operating voltages of the speed integrator cathode follower tube 150. By selecting the correct voltages for that tube, it cannot be driven sufficiently to cause more than a few percent change in speed. Any attempt to drive it further results either in cut-off or saturation of the cathode follower. It is preferred, however, to provide this limitation in the effective value of the off-phase and off-speed signals by means of the contact potential of the rectifiers 184 so that any potential produced in the off-speed integrator above a preselected amount will be shunted to ground. In order to provide the desired sensitivity the maximum off-speed and off-phase signals become of a magnitude such that a dangerously large change in slave speed, say 10% or more, is required to provide a balancing speed error signal. By limiting the voltage which the off-speed integrator or the phasing mechanism can apply to the junction of resistors 140 and 142 and thus to the amplifier 20, a limit is established for the off-speed signal which must be supplied by the frequency sensing governor 18*a* to the junction of resistors 78 and 80 to be combined with the off-phase and off-speed integrated signals on their way to the amplifier 20 to oppose and balance or reduce to zero the effect of off-speed integrated and off-phase signals. It will be understood that starting with the frequency sensing governor in an on-speed condition and putting out zero volts to the amplifier 20, if the synchronizer with its off-phase or off-speed signals were to drive the slave to a different speed such a different speed would be an error in speed to the governor and will result in an opposing signal from the frequency sensing governor. Hence, by limiting the voltage which the off-speed integrator is capable of supplying and thus the governor speed error signal necessary to be combined with the off-speed integrated and off-phase signals to neutralize the integrator signal and stop further pitch change, it is possible to limit the extent of the off-speed excursions of the slave in its attempt to follow the master. The rectifiers 176 are inserted to prevent any slight voltage variations of the off-speed integrator tube 150 from entering the control system. The rectifiers 176 require the tube 150 to provide a signal which is greater than its output for synchronous operation but less than its output for a single pulse of off-speed before that signal can be conducted to the combining network.

From the above description it will be observed that each of several, say four, propellers have been provided with speed control mechanism whose speed setting is determined by each individual throttle setting, the speed setting increasing with increasing throttle opening. Synchronizing and phasing mechanism has been provided comprising one saw-tooth wave forming device connected with the master propeller and three sampling devices, one for each slave propeller. The sampling devices compare the phase of the respective slave propeller with that of the master by sampling the master saw-tooth wave to provide a phase error signal and also count the revolutions of speed difference to provide a speed error integrated signal. The phase error and the integrated speed error signals are combined to provide a speed correction action to the slave propeller pitch control and restore in-phase operation.

The above described synchronizer and individual governor control will control down only to a low pitch position determined by a mechanical low pitch stop 244. Operation below this low pitch stop position 244 to a starting or idling position and even down to reverse position is controlled by a Beta control device which is essentially a potentiometer 26 positioned by throttle lever 84 and a potentiometer 24 positioned by the propeller blades 12 or servo mechanism 23. These potentiometers are connected to provide a signal to the amplifier such as 20 through the resistors 78 and 80 to provide a pitch changing signal such that the propeller pitch will follow the movements of, and in effect be positioned by the throttle lever 84. The throttle is arranged so as to reduce the throttle opening down to a starting or idling position and arranged so that continued movement in the same direction will increase the throttle opening as the propeller moves into reverse pitch position. When the power lever is placed anywhere between idle and full reverse, a Beta switch 250 is closed. This switch supplies 28 volts ship's supply to energize the Beta solenoid 252, Fig. 2. This will connect high pressure oil from the pumps 112 to the piston 254 to remove the mechanical low pitch stop lock for low pitch stop 244. Removal of the low pitch stop 244 will close switch 256 to connect the 28 volts ship's supply to one side of the Beta relay 240, the other side of which is connected through line 260 with a Beta arming switch 118 which is closed at all blade positions below a predetermined pitch above the low pitch stop position. Energizing the Beta relay, as indicated above, switches the input of the amplifier which is used for governing from the speed error signal to a blade angle error signal. As indicated above, the blade error angle signal is obtained by comparing the outputs of a blade actuator potentiometer with a throttle lever actuated potentiometer. The throttle lever actuated potentiometer in effect shifts the ground connection for an otherwise ungrounded output portion of the power supply to thus in effect, change the value of the negative voltage of the power supply to the potentiometer. Actuation of the Beta solenoid 252, Fig. 2 will, in addition to removing the low pitch stop 244, also actuate piston 262 and lever 264 to disable the overspeed governor 266 so that the propeller will not inadvertently increase pitch in the reverse pitch position.

Manual feathering is initiated by pushing valve 27, Fig. 2, to drain oil from one side of the servo cylinder and shut off pressure oil not required for the feathering operation. To top off the feathering operation, the auxiliary pump 268 driven by electric motor 270 is actuated to supply oil as the main pump 212 slows down.

Unfeathering is obtained by allowing valve 27 to return to the position shown in Fig. 2 and energizing the auxiliary motor 270. Ship power of 115 vole 400 cycles will supply the power for underspeed signals to the amplifier and proportional solenoid until the generator 16 provides sufficient voltage to operate solenoid and shift the power source to the respective generators and the control to the electronic governors.

It is to be understood that the invention is not limited to the specific embodiment herein illustrated and described, but may be used in other ways without departure from its spirit as defined by the following claims.

We claim:

1. In a phasing mechanism for a master and a slave device having means responsive to an out-of-phase relation of said devices for creating an off-phase signal proportional to the extent of the phase lag or lead for changing the speed of the slave device to restore an in-phase condition, said signal becoming, during off-speed operation of said slave relative to said master, alternately an increase and decrease speed signal as the slave repeatedly passes the on-phase and the 180° out-of-phase relation with respect to the master, means creating an off-speed signal each time the slave passes the 180° out-of-phase relation, means combining said off-speed signals with said off-phase signals to change the slave speed in one direction to eliminate the off-speed operation and return the control to the off-phase signals, means manually selecting said slave speed and means limiting the effective value of said off-speed signals to prevent changing said slave speed more than a predetermined amount from said selected speed.

2. A device as claimed in claim 1 in which said limiting means is connected with said off-phase signals to prevent changing the selected speed more than a predetermined amount with the off-phase signals.

3. A mechanism as claimed in claim 2 in which the maximum off-speed and off-phase signals are of a magnitude capable of causing a change from said selected speed of more than 5% and said limiting means limit the maximum effective value of said off-speed and off-phase signals to limit the maximum speed change to the order of 3% of the selected speed.

4. A mechanism as claimed in claim 1 in which said signals are electrical signals and the limiting means includes a pair of rectifiers having a predetermined contact potential and arranged to conduct in opposite directions in parallel paths and connecting said off-speed signal with a by-pass.

5. In a phasing mechanism for a master and a slave device, each having an individual speed governor, means for manually selecting the respective speed above and below which each governor will produce a speed error signal for controlling the speed of its respective device, means producing an off-phase signal responding to the direction and extent of the phase difference between the master and the slave, means combining said off-phase and said slave speed error signals to change the slave speed and bring it into synchronism and phase with said master and means limiting the effective value of said off-phase signal to prevent changing the slave speed more than a predetermined amount with said off-phase signals.

6. A mechanism as claimed in claim 5 including means producing an off-speed signal for each revolution of the slave relative to the master, means combining said off-speed and said off-phase signals and said speed error signals to provide a governor biasing signal to change the speed of said slave, and means limiting the value of both said off-phase and said off-speed signals to limit speed changes from said manually selected slave speed to a predetermined amount.

7. A mechanism as claimed in claim 6 in which said signals are electrical signals and said limiting means includes a pair of opposed rectifiers having a predetermined contact potential connected in parallel and connected to act as a by-pass for both said off-speed and said off-phase signals.

8. In a synchronizing mechanism for a master and a slave device, said slave having a speed governor, means for manually selecting the slave speed above and below which the governor will produce a speed error signal for controlling the speed of the slave, means producing an off-speed signal responding to the direction and extent of the speed difference between the master and the slave, means effecting a speed change of said slave with said off-speed signal, means balancing said off-speed signal with said error signal to change the slave speed to bring it into synchronism with said master, means limiting the effective value of said off-speed signal to prevent changing the slave speed more than 3% from said manually selected speed with said off-speed signals.

9. In a phasing mechanism for a master and a slave device having means responsive to an out-of-phase relation of said device for creating an off-phase signal proportional to the extent of the phase lag or lead for changing the speed of the slave device to restore an in-phase condition, said signal, during off-speed operation of the slave relative to the master, being alternately an increase and decrease signal as the slave repeatedly passes the on-phase and the 180° out-of-phase relation with respect to the master, means utilizing the change in the off-phase signal each time the slave passes the 180° out-of-phase relation to create off-speed signals, means combining said off-speed signals with said off-phase signals to change the slave speed in the direction to eliminate the off-speed operation and return the control to the off-phase signals, means manually selecting said slave speed and means limiting the effective value of said off-speed signals to prevent changing said slave speed more than a predetermined amount from said selected speed.

10. A mechanism as claimed in claim 9 in which when the master and slave are operating in synchronism the off-phase signal alone changes the speed of the slave device to restore an in-phase condition from substantially all positions between the in-phase and the 180° out-of-phase relation, said signal limiting means also effective to limit said off-phase signal.

11. In a phasing mechanism for a master and a slave device having means responsive to an out-of-phase relation of said device for creating an electrical off-phase signal proportional to the extent of the phase lag or lead for changing the speed of the slave device to restore an in-phase condition, said signal, during off-speed operation of the slave relative to the master, being alternately positive and negative to provide increase and decrease signals as the slave repeatedly passes the on-phase and the 180° out-of-phase relation with respect to the master, means utilizing the change in the off-phase signal each time the slave passes the 180° out-of-phase relation to create positive and negative off-speed signals dependent on the direction of change, means combining said off-speed signals with said off-phase signals to change the slave speed in the direction to eliminate the off-speed operation and return the control to the off-phase signals, means manually selecting an electrical speed responsive signal regulating said slave speed, means combining said manually selected signal and said combined off-phase and off-speed signals and means limiting the effective value of said off-speed signals to prevent changing said slave speed more than a predetermined amount from said selected speed.

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