Nov. 25, 1969 R. E. NELSON ET AL 3,479,822

ENGINE SYNCHRONIZER

Filed March 27, 1968 3 Sheets-Sheet 1

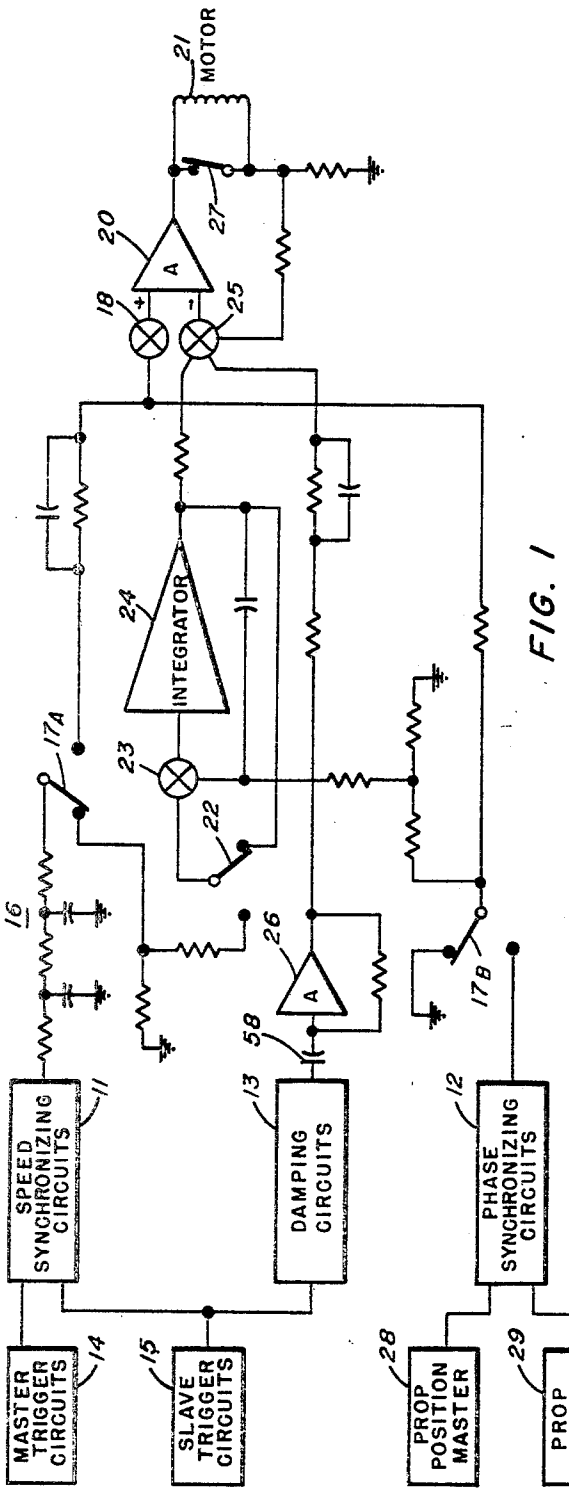

FIG. 1

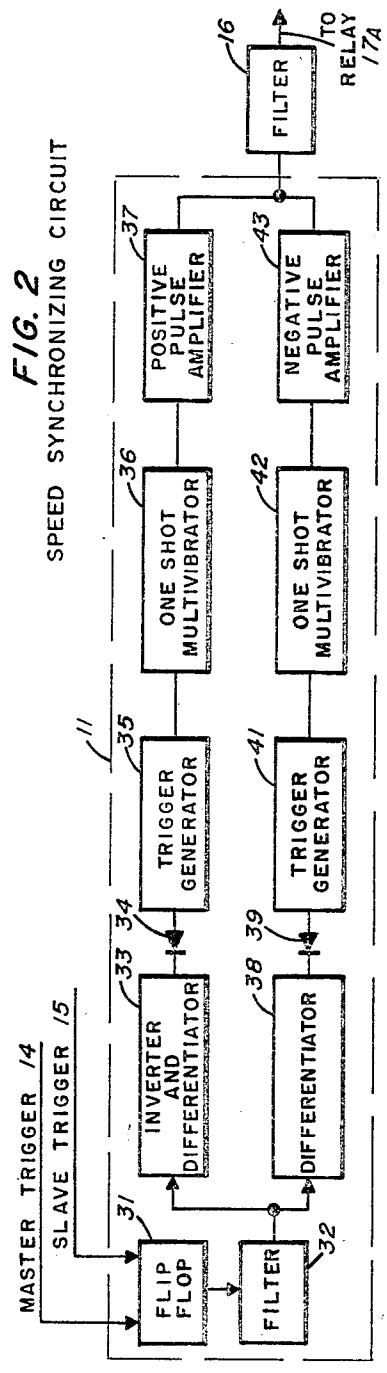

FIG. 2

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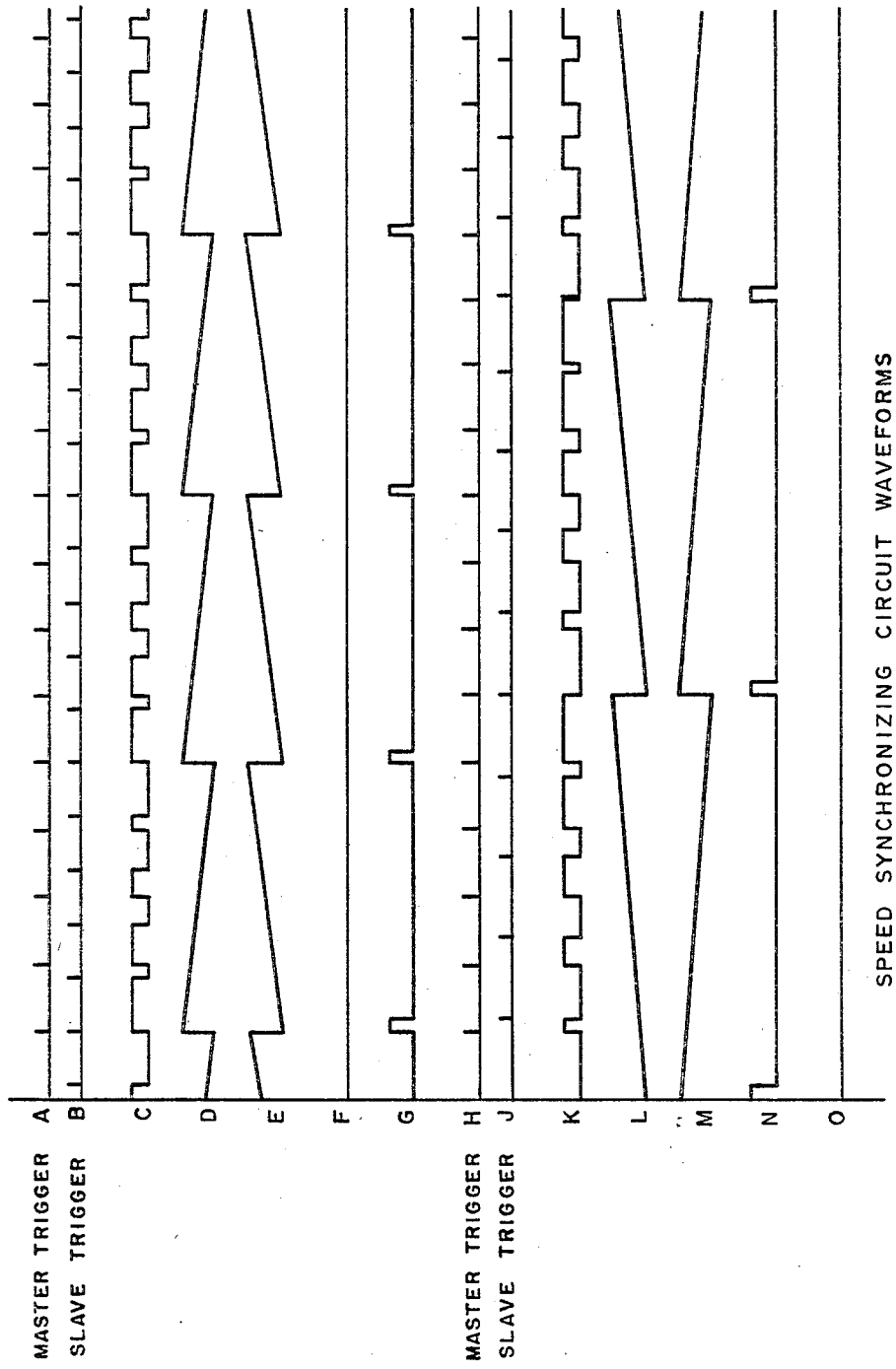
MASTER TRIGGER
SLAVE TRIGGER
A
B
C
D
E
F
G
MASTER TRIGGER
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SPEED SYNCHRONIZING CIRCUIT WAVEFORMS

FIG. 3

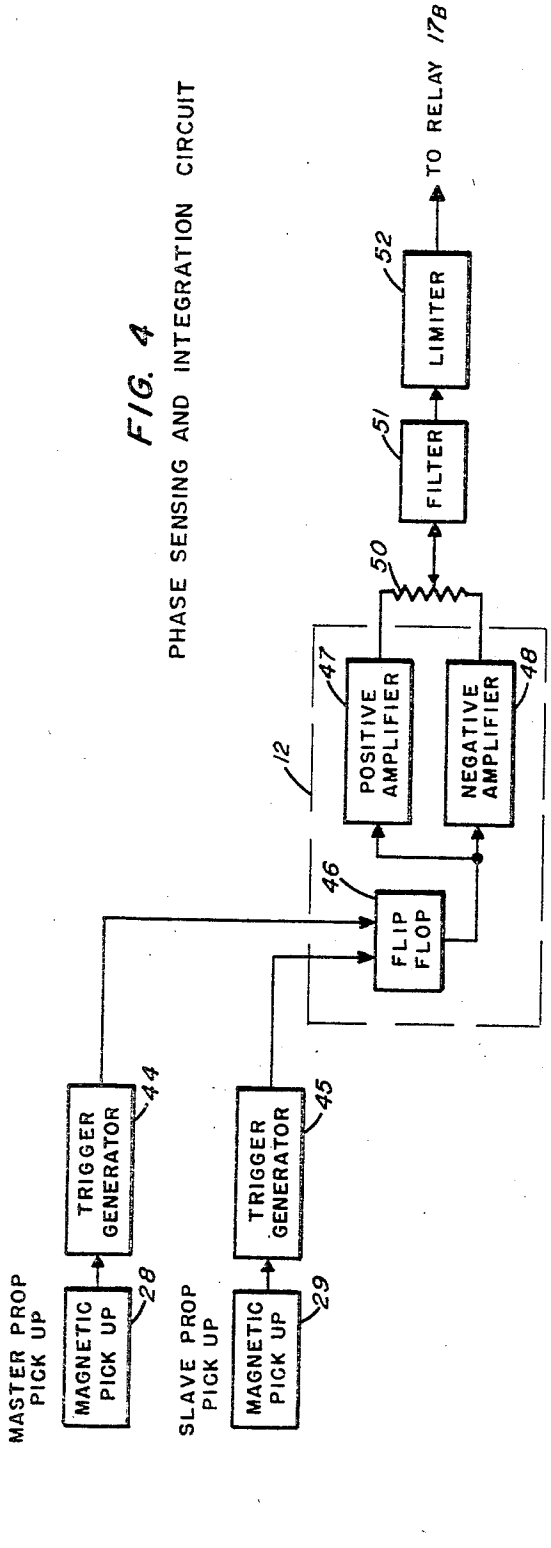

FIG. 4
PHASE SENSING AND INTEGRATION CIRCUIT

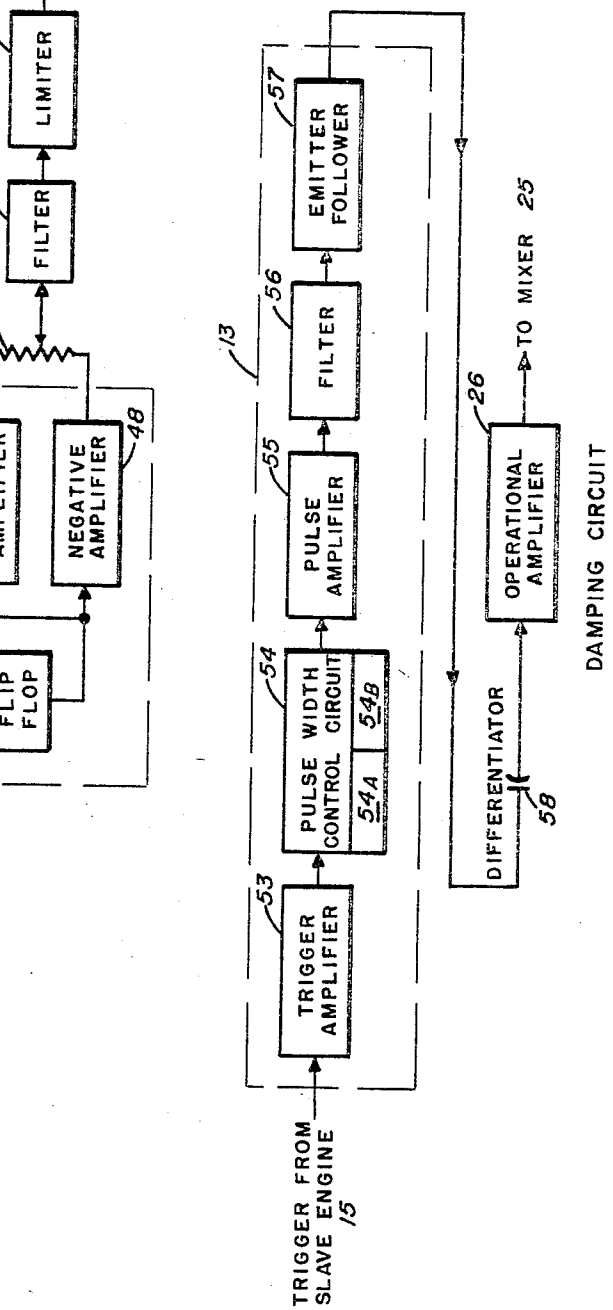

FIG. 5
DAMPING CIRCUIT

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3,479,822

ENGINE SYNCHRONIZER

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Int. Cl. F02b 73/00; F01b 21/00; B64c 11/46
U.S. Cl. 60—97 7 Claims

ABSTRACT OF THE DISCLOSURE

A control system which provides for speed synchronizing and phase synchronizing two or more turboprop engines by applying current to the windings of a torque motor which is attached to the fulcrum point of the engine governor system. By energizing the torque motor in a direction to aid or oppose the centrifugal governor weight, more or less propeller pitch may be essentially artificially introduced to increase or decrease motor speed.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

When two or more engine-propeller combinations are rotating at slightly different speeds, a vibration beat develops, the frequency of which is dependent upon the speed difference which exists between the engines. To eliminate the detrimental effects of vibration beat and noise in an aircraft, automatic synchronizer mechanisms are employed to maintain the engines in speed synchronism with each other. In addition, it has been found desirable both from the vibration and the noise standpoint not only to synchronize the several engine propellers as to speed but also to maintain a selective phase relation between the propellers themselves. Mechanisms responsive to speed alone are not capable of maintaining the required phase relationship even when such mechanisms are capable of maintaining speed synchronization.

SUMMARY OF THE INVENTION

In order to accomplish the above desired results, applicant has invented a new and improved synchronizing circuit which automatically, accurately, and electronically synchronizes a plurality of engines not only for speed but also for phase.

There are three operational modes of the control: damping, speed synchronization, and phase synchronization. The damping mode provides a signal to reduce the effect of sudden changes in propeller speed due to transient loading conditions, and provides a stabilizing factor for power transients. The damping signal is developed by differentiating the voltage which represents propeller, or turbine speed. Steady state speeds develop no signal, but sudden changes in speeds cause a large opposing signal voltage to be developed.

The speed synchronization mode of operation is one in which the control acts only to provide speed synchronization of the slave engine with the master engine.

It is actually a bias function where a signal representing the difference in speed of the two engines is used to provide a bias level for the operation of the control. The synchronizing signal is obtained by integration of the signal which respresents the different between engine speeds. The operation of the integrator is such that its output keeps increasing as long as the slave engine speed is greater than the master engine speed, and it decreases as long as the slave engine speed is less than the master engine speed. The integrator output voltage remains constant only when the two speeds are equal and during the synchronization mode of operation, the damping function is also provided to aid in speed stabilization.

The phase synchronization mode is the mode whereby phase synchronization of the master engine propeller and the slave engine propeller actually takes place. This mode fulfills the design objective of the control. A degree of redundancy exists somewhat in the speed synchronizing and the phase synchronizing modes in that one would expect the propellers to be synchronized when the engine speeds are synchronized. The speed synchronization mode actually affects a very tight governing control mode. Speed synchronization is effectively obtained to the degree of "zero" average speed error. In the absence of any transient conditions, a degree of blade phase synchronization is attained in this mode. In reality, however, transients do cause momentary speed differences, and propeller phase runout, which can be controlled only by the signals applied during the phase synchronization mode. The speed synchronization mode is therefore used to obtain propeller speed synchronization and a reasonably stable phase relationship. Once the propeller speeds have been synchronized by the speed synchronization mode, however, the control can be placed in the phase synchronization mode. In this mode two new signals come into play which accomplish a phase synchronization of the two propellers. A signal representing the difference between the engine speeds is used to help maintain speed synchronization, and a signal which represents the phase difference between the blades of the slave propeller and their respective counterparts on the master propeller, are summed to provide a very tight control signal. In the phase synchronization mode of operation there is no speed synchronization signal applied; the damping signal is provided, however, to assist in stabilization. In addition, a signal which represents the integral of phase angle is provided to eliminate the droop allowed by the proportional phase signal.

An object of the present invention is the provision of the engine synchronizing circuit which obtains synchronization of a plurality of engines both as to speed and phase.

Another object of the invention is the provision of a damping mode to reduced the effect of sudden changes in propeller speed due to transient loading conditions.

Another object is the provision of a synchronizing circuit which energizes a torque motor attached to the fulcrum point of the speed governor.

A further object is the provision of a synchronizing circuit for reducing the noise and beat frequency in the aircraft cabin.

Still another object is the provision of a synchronization circuit which provides three operational modes of control.

Yet another object of the invention is the provision of a synchronization circuit in which the synchronizing sig-

nal is obtained by integration of a signal which represents the difference between engine speeds.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which like reference numerals designate like parts throughout the figures thereof and wherein:

FIG. 1 shows a block diagram of the over-all system;

FIG. 2 shows a block diagram of the speed synchronizing circuit;

FIG. 3 shows the waveforms present in the synchronizing circuit;

FIG. 4 shows a block diagram of the phase synchronizing circuit; and

FIG. 5 shows a block diagram of the damping circuit.

Referring now to FIG. 1, there will be seen the three major circuits which are responsible for the three modes of operation of the device; namely, a speed synchronizing circuit **11**, a phase synchronizing circuit **12**, and a damping circuit **13**. The speed synchronizing circuit **11** has two inputs, one from a master trigger circuit **14**, and the other from a slave trigger circuit **15**. The output of speed synchronizing circuit **11** passes through an integrating circuit **16** and is applied to one of the arms of phase synchronizing relay **17***a*. From the phase synchronizing relay the signal then passes to a mixer **18** and is finally applied to an amplifier **20**. Torque motor **21** is connected to the output of amplifier **20** so that action of the motor is responsive to the amplifier's output.

An alternate output from phase synchronization relay **17***a* leads to synchronization relay **22**, the arm of this relay in turn being connected to a mixer **23**, the output of which serves as an input to an integrator **24**. The output of integrator **24** then leads to another mixer **25** whose output is applied as a second input to amplifier **20**.

Turning now to the damping channel, it will be seen that the output of slave trigger circuit **15** in addition to being applied to component **11**, is also applied as an input to damping circuit **13**, the output of this circuit being in turn applied to an amplifier **26** whose output forms another input to mixer **25**. Connected across motor **21** is a damping relay **27**.

The third and final mode of operation, that of phase synchronization, results when a signal from the master propeller position circuit **28** and a signal from the slave position propeller circuit **29** are both applied as inputs to the phase synchronizer circuit **12**. The output of phase synchronizing circuit **12** is applied to relay contact **17***b* where the signal is split into two channels, a portion of the signal being applied to mixer **23** and the other portion of the signal being applied to mixer **18**.

Referring now to FIG. 2, there will be seen a block diagram of the speed synchronizing circuit **11**. Here master trigger signal **14** and slave trigger signal **15** are both applied as inputs to a flip flop **31** the output of which is applied to an RC filter **32**. The output of filter **32** is divided into two parallel channels one of which consists of an inverter and differentiator **33**, a diode rectifier **34**, a trigger generator **35**, a one-shot multivibrator **36**, and a positive pulse amplifier **37**. The other channel consists of a differentiator **38**, diode rectifier **39**, trigger generator **41**, one-shot multivibrator **42**, and a negative pulse amplifier **43**. The outputs of both of these parallel channels, positive pulse amplifier **37** and negative pulse amplifier **43**, are applied to filter **16** (FIG. 1) from which the signal is applied to synchronizing relay **17***a*.

In FIG. 4 there is shown a block diagram of the phase sensing and integration board including the phase synchronization circuit **12** shown in FIG. 1. A magnetic pickup device **28**, which is activated by the master propeller as it rotates, generates a signal which is applied to a trigger generator **44** the output of which is applied to a flip-flop **46**. Likewise, magnetic pickup **29**, which is activated by the slave propeller as it rotates, generates a signal which is applied to a trigger generator **45**, the output of which is also applied as an input to flip-flop **46**. The output of flip-flop **46** is divided into two parallel channels, one of which is a positive amplifier **47** and the other a negative amplifier **48**, the output of these amplifiers being combined and applied across a potentiometer **50**. The sliding arm of potentiometer **50** picks up the combined signal and applies it to a filter **51** and in turn to a limiter **52** before it is applied to phase synchronization relay **17***b* (FIG. 1).

The elements making up the damping circuit **13** and the associated components therewith are shown in block diagram in FIG. 5. The slave trigger **15** is applied to a trigger amplifier **53**, a pulse width control circuit **54**, a pulse amplifier **55**, a filter circuit **56**, and an emitter follower **57** before being applied to a differentiator **58** and an operational amplifier **26** (FIG. 1). The output of amplifier **26** is then applied via mixer **25** and amplifier **20** to the motor windings **21**.

Referring now to the operation of the device by a description of the three operational modes of control, that is, speed synchronization, phase synchronization and damping, it can be seen that flip-flop circuit **31** is set by the master speed trigger **14** and is reset by the slave speed trigger **15**. These triggers are generated by torque pickup devices associated with each of the motors and it will be assumed that the repetition rate of these triggers is proportional to their respective engine r.p.m.'s. Traces A through G of FIG. 3 illustrate a situation where the slave engine's speed is greater than the master, and traces H through P illustrate the situation where the slave speed is lower than the master. As the flip-flop **31** is triggered alternately from one stable state to the other, the waveforms of trace C and trace K will result. This signal is then filtered by filter **32** to divide the signals shown by trace D and trace L. These sawtoooth waveforms are a result of phase slippage, or speed differences, between the two engines as the speeds approach synchronization; that is, as slave speed minus master speed approaches zero, the frequency of the sawtooth waveform decreases toward zero, and only at speed synchronization does the sawtooth actually disappear.

Thus the sawtooth created after it has been filtered by filter **32** is applied as inputs to inverter differentiator **33** and the differentiator **38**, the sawtooth thus created being inverted by inverter **33**. This circuit forms a portion of the polarity sensing function of the sawtoooth. Each of the delay multivibrators is triggered by the negative going step from the sawtooth waveform. It is for this reason that the inverted waveform is used to generate a trigger at trigger generator **35**. The sawtooth waveform of trace E, FIG. 3, is differentiated by differentiator **33** and the negative spike produced, causes a trigger pulse to be generated by trigger generator **35** (trace G). In the other channel the waveform of trace L, FIG. 3, is differentiated by differentiator **38**, and the negative spike produced causes a trigger pulse to be generated by trigger generator **41**. Note that triggers are produced at generator **35** only when slave speed is greater than master speed, and that triggers are produced at trigger **41** only when master speed is greater than slave speed. The one-shot multivibrator **36** is triggered by the puse from generator **35**, while the multivibrator **42** is identical to the one triggered by **35** except that it is triggered by **41**. The output of multivibrator **36** drives a positive pulse amplifier **37** to produce a positive pulse which is applied at the collector of the output stage of negative pulse amplifier **43** while the outputs of multivibrator **42** drives negative pulse amplifier **43** to produce a negative pulse also at the collector of the final stages of that component. The waveform at this point is therefore a series of positive or negative pulses proportional to slave speeds minus master speed, both in polarity and frequency. Their pulse width is constant and determined by the one-shot multivibrators **36** and **42**. The filter network

16 which is connected to the collector of the final stage of amplifier 43 is used to provide a DC signal proportional to slave speed minus master speed.

The phase synchronization mode of operation, as shown in block diagram form in FIG. 4, is accomplished by a magnetic pickup located on the engine gear box in close proximity to the propeller shaft, so that the pickup senses the passage of a metal slug which is indexed with respect to a blade of the propeller. The trigger thus generated provides information regarding the propeller position. This information is converted to a signal which represents the phase difference between the master engine propeller and the slave engine propeller. Thus, the pulse from the master engine pickup 28 is converted to a trigger by trigger generator 44 which is used to reset the flip-flop circuit 46 while the pulse, and subsequent trigger from the slave engine pickup 29 and trigger 45, sets the flip-flop 46. A zero phase relationship between master propeller and slave propeller in reality is a 180° relationship in terms of one revolution of the propeller. The flip-flop 46 is triggered once per revolution of each propeller, therefore with 180° relationship, the flip-flop output is a square wave with a 50 percent duty cycle. As the phase relationship between propellers changes, the duty cycle of the flip-flop varies proportionately. The positive going portion of the flip-flop 46 output causes a positive voltage to appear at the output of positive amplifier 47, while the negative portion of the flip-flop output causes a negative voltage to appear at the output of negative amplifier 48. These outputs are impressed across a phase adjust potentiometer 50, such that the final signal is a function of true propeller phase, and potentiometer position. The rectangular waveform from the potentiometer is filtered by filter 51 to provide a DC signal proportional to propeller phase angle and is clamped by limiter 52 to limit the maximum signal output from the circuit. The signal produced by this cricuitry is the propeller phase signal and is passed on to relay 17*b*.

The damping mode of operation, shown in blank form in FIG. 5, can be thought of as the transient suppression or the speed stabilization function of the control. A pulse from the slave engine trigger circuitry 15 is fed to an amplifier circuit 53. The following stage is a pulse width control circuit 54 which is composed of two stages, 54*a* and 54*b*, and the pulse produced by trigger amplifier 53 turns on stage 54*a* for a very short duration, but long enough to charge a particular condenser to minus 25 volts. As long as the condenser has a negative charge, stage 54*b* is biased off. When the shock pulse disappears from its input, stage 54*a* returns to its non-conducting state and the condenser begins charging towards positive 25 volts high voltage. When its charge voltage approaches approximately plus 1 volt, stage 54*b* is biased to on the "ON" condition. The "OFF" time of stage 54*b* is thus determined by the time constant of an RC circuit made up of a resistance and the particular condenser mentioned. This circuit functions somewhat as a one-shot multivibrator, but it has the advantage of being capable of greater than 100 percent duty cycle, since it has effectively a negative reset time in that it can be trigered at any time during its cycle and the resulting time delay will be a constant starting at the trigger pulse. The constant width pulse produced by the circuit 54 is then amplified by pulse amplifier 55 and filtered by filter 56. The resulting DC signal is a voltage proportional to the slave engine speed. The damping circuit, therefore, merely functions as a frequency DC converter. The emitter follower 57 prevents loading of the filter circuitry 56 and provides a low driving impedance for differentiating capacitor 58. Since the speed signal is differentiated by 58, the signal at this point represents only the changes in speed with respect to time. After the speed signal leaves differentiator 58, it is amplified by amplifier 26 whose output is then passed on to mixer 25.

The circuitry which makes up the master trigger signal 14 and the slave trigger signal 15 consists simply of two identical trigger amplifiers which accept inputs from the torque meter pickups of the slave and master engines, and provide output pulses for each of the input pulses sufficient to drive the appropriate control circuitry. The input signals are generated by the passage of torque meter excited teeth in close proximity to the torque meter pickup, the exciter being a gear-like disk attached to the engine drive shaft, and the torque meter pickup being a fairly conventional magnetic-type sensing device. The output of these trigger amplifiers comprise a signal from master trigger circuits and slave trigger circuits 14 and 15 and applied at inputs to phase synchronizing circuit 11.

The output circuitry of the device is an operational amplifier 20 with a driver output stage which converts the voltage out of the amplifier to a current sufficient to drive the torque motor 21 in the propeller governor.

From the above description of the structure and operation of the present invention, it is obvious that the device offers a vast improvement over prior art synchronizing systems. Not only will the invention provide speed synchronization of two propellers but it will also provide phase synchronization and damping against sudden changes in propeller speed due to transient loading conditions. The device accomplishes its synchronizing function entirely electronically, is extremely sensitive and is quick acting so that in the event of even small differences between the master and slave engines the device rapidly compensates for this difference accurately and with a minimum of overshoot.

What is claimed is:

1. An electronic propeller control system comprising
   - means for generating a signal indicative of master engine speed;
   - means for generating a signal indicative of slave engine speed;
   - means for applying the master speed signal and the slave speed signal to a speed synchronizing circuit;
   - means for generating a signal indicative of propeller position of the master engine;
   - means for generating a signal indicative of propeller position of the slave engine;
   - means for applying the master position signal and the slave position signal to a phase synchronizing circuit;
   - means for applying the slave speed signal to a damping circuit; and
   - motor means on the slave engine for receiving the output of the speed synchronizing circuit, the phase synchronizing circuit, and the damping circuit for synchronizing the slave engine with the master engine.

2. The system of claim 1 wherein the means for generating a signal indicative of master engine speed consists of a torquemeter pickup attached to the master engine with the output of the torquemeter driving a trigger generator.

3. The system of claim 2 wherein the means for generating a signal indicative of slave engine pickup consists of a torquemeter pickup attached to the slave engine with the output of the torquemeter driving a trigger generator.

4. The system of claim 3 wherein the speed synchronizing circuit comprises a flip-flop circuit which is alternately triggered from one stable state to the other stable state by the master speed signal and the slave speed signal;
   - parallel signal channels fed by flip-flop, each channel having a differentiator, a trigger generator, a multivibrator, and a pulse amplifier so that one channel produces a positive pulse and the other channel produces a negative pulse; and
   - means for combining the positive and negative pulses to produce a signal indicative of the speed difference between the master and slave engines.

5. The system of claim 4 wherein the phase synchronizing circuit comprises a flip flop circuit which is alternate-

ly triggered from one stable state to the other stable state by the propeller position signal from the master and slave engines;

a positive amplifier and a negative amplifier connected to the output of the flip flop; and

a potentiometer connected to the output of the two amplifiers to produce a signal proportional to the propeller phase angle.

6. The system of claim **5** wherein the damping circuit comprises a trigger amplifier, a pulse width control circuit, a pulse amplifier, an emitter follower, and a differentiator, all connected in series to produce a signal proportional to slave engine speed.

7. The system of claim **6** wherein the motor means is

attached to the fulcrum point of the slave engine governor system and acts to aid or oppose the centrifugal governor weight.

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170—135.29