

PATENT SPECIFICATION

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(54) CONTROL SYSTEM FOR A PLURALITY OF ENGINES

(71) We, SUNDSTRAND CORPORATION, a corporation organised and existing under the laws of the state of Delaware, United States of America, of 4751 Harrison Avenue, Rockford, Illinois 61101, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention relates to the control of a plurality of engines in a power plant and, more particularly, to a control circuit for assuring that power provided to a common load is properly shared by the engines.

Output shafts of a plurality of engines are often interconnected to provide isochronous operation and to provide power to a common load. A control system is usually provided to divide the load equally between the two engines. Since the engines are made to operate at a common speed, the load is balanced or equally shared by increasing or decreasing the torque output from each engine. Most control systems are of the hydraulic or pneumatic type. Prior art systems for load sharing of coupled engines employ droop control wherein the output of the engine providing less than its share of torque is increased to match the output torque provided by the other engine.

Helicopter power plants often employ two similar engines, such as gas turbine engines which, coupled together for isochronous operation, provide power to a common load. The most efficient operation of the plant is realized when each engine is supplying half of the torque requirement.

The invention provides a power plant having a plurality of engines the outputs of which are coupled together for isochronous operation, each engine providing an output torque proportional to a control signal and being controlled by a control circuit for

assuring that the torque is shared between the engines, wherein the control circuit comprises: means for generating a torque difference signal proportional to any difference in the output torques between the engines; means for generating a speed error signal proportional to any difference between a selected reference speed and the actual speed of the engines; and means for combining the speed error signal with the torque difference signal to provide a control signal for each engine.

The output shafts of the engines of the power plant are interconnected for isochronous operation. Each engine provides its share of power to the load by increasing or decreasing the magnitude of its output torque in response to the control signal. Each control signal is responsive to the difference between the selected reference speed and the actual isochronous speed and any torque difference between the engines. Each control signal is preferably applied to a fuel control circuit which controls the output torque of the associated engine in response to its control signal.

Preferably the invention provides a control circuit which assures that the power delivered to the load from two engines is equally divided during isochronous operation. Advantageously the power is equally divided both during steady state operation and during transient disturbances.

The invention is hereinafter particularly described, by way of example only, with reference to the drawing of which:

Power plant 10 includes similar engines 12-1 and 12-2. The engines each have an output shaft 14-1 and 14-2 which are coupled to gears 16-1 and 16-2, respectively. Gears 16-1 and 16-2 drive gear 18 in an isochronous manner to provide power to common load 20. Engines 12-1 and 12-2 may be gas turbine engines specifically adapted to provide power to a helicopter load 20

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being the helicopter rotor. The power contributed to load 20 by each engine is usually equal. However, other proportions may be established as will be apparent when considering the system discussed below.

The power developed by engines 12-1 and 12-2 is directly proportional to the fuel provided thereto by fuel control circuits 22-1 and 22-2. The amount of fuel so provided is proportional to the magnitude of control signals applied to the fuel control circuits 22-1 and 22-2, respectively.

The speed at which the output shafts 14 rotate is controlled by a signal Δ speed from summer 24. The signal Δ speed represents the difference between a selected reference speed and the actual speed. The signal representing the desired or reference speed is provided by reference speed circuit 26 and the signal representative of the actual speed is provided by speed sensor 28. When the actual speed equals the reference speed, the signal Δ speed from summer 24 is zero.

The Δ speed signal from summer 24 is provided to proportional control channels 30-1 and 30-2 and integral control channels 32-1 and 32-2. The proportional control channels 30-1 and 30-2 are connected in parallel with integral control channels 32-1 and 32-2 respectively. The outputs of the channels are applied to summers 34-1 and 34-2, respectively. The outputs of summers 34-1 and 34-2 are the control signals for fuel control circuits 22-1 and 22-2, respectively.

The torque provided on the output shafts 14-1 and 14-2 is sensed by torque sensors 36-1 and 36-2, respectively; and a signal representing the torque of each shaft is provided to summer 38. The output of summer 38 is a signal, Δ torque, which represents the torque difference or imbalance between the shafts. The output of summer 38 is coupled to the system through switch 40 which is normally closed when both engines are operating. The torque difference signal from summer 38 is of one polarity or sense and is applied to proportional control 30-1 and integral control 32-1 through scale factor 42-1. The torque difference signal of the opposite polarity or sense, as provided by an inverting amplifier 44 is applied to proportional control 30-2 and to integral control 32-2 through scale factor 42-2. If scale factors 42-1 and 42-2 are equal, the signal representing the torque difference applied to proportional control channel 30-1 and integral control channel 32-1 is equal to and of opposite sense or polarity from the signal representing the torque difference applied to proportional control channel 30-2 and integral control channel 32-2. When the torque on output shaft 14-1 is equal to the torque on output shaft 14-2, the output from summer 38 and inverter 44 is zero.

The operation of proportional control chan-

nel 30-1 and integral control channel 32-1 will now be considered, it being understood that proportional control channel 30-2 and integral control channel 32-2 operate in a similar manner. Proportional control channel 30-1 includes a summer 46-1 and proportional control multiplexer 48-1 which acts as an active gain and compensation circuit. The signals Δ speed for op amp 49-1 and Δ torque from summer 38 are applied as inputs to proportional control multiplier 48-1 through summer 46-1. The output of proportional control multiplexer 48-1 is applied to summer 34-1. The multiplier is selected in accordance with the dynamic operating conditions of the system. During steady state operation the output from proportional control multiplier 48-1 is zero. The output from proportional control multiplier 48-1 increases or decreases fuel control 22-1 through summer 34-1 in response to the transient disturbances.

Integral control channel 32-1 includes a summer 50-1 an integrator 52-1 and a K multiplier 54-1. The output from integrator 52-1 is applied to multiplier 54-1 and is a non-zero value during steady state operation. The time constant of the integrator 52-1 is selected to be sufficiently long so as not to be affected by transient disturbances. The gain of multiplier 54-1 is selected to provide an output of suitable magnitude for steady state operation.

Generally, the torque provided by engine 12-1 equals the torque provided by engine 12-2. However, this is not a requirement. For example, by the appropriate selection of scale factors 42-1 and 42-2, load sharing between the two engines may be established for any particular proportions. The proportional side would also require a scale factor to accomplish this object.

WHAT WE CLAIM IS:

1. A power plant having a plurality of engines the outputs of which are coupled together for isochronous operation, each engine providing an output torque proportional to a control signal and being controlled by a control circuit for assuring that the torque is shared between the engines, wherein the control circuit comprises: means for generating a torque difference signal proportional to any difference in the output torques between the engines; means for generating a speed error signal proportional to any difference between a selected reference speed and the actual speed of the engines; and means for combining the speed error signal with the torque difference signal to provide a control signal for each engine.

2. A power plant according to claim 1, wherein the torque is shared equally between the engines.

3. A power plant according to claim 1 or claim 2, wherein there are two engines.

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being the helicopter rotor. The power contributed to load 20 by each engine is usually equal. However, other proportions may be established as will be apparent when considering the system discussed below.

The power developed by engines 12-1 and 12-2 is directly proportional to the fuel provided thereto by fuel control circuits 22-1 and 22-2. The amount of fuel so provided is proportional to the magnitude of control signals applied to the fuel control circuits 22-1 and 22-2, respectively.

The speed at which the output shafts 14 rotate is controlled by a signal Δ speed from summer 24. The signal Δ speed represents the difference between a selected reference speed and the actual speed. The signal representing the desired or reference speed is provided by reference speed circuit 26 and the signal representative of the actual speed is provided by speed sensor 28. When the actual speed equals the reference speed, the signal Δ speed from summer 24 is zero.

The Δ speed signal from summer 24 is provided to proportional control channels 30-1 and 30-2 and integral control channels 32-1 and 32-2. The proportional control channels 30-1 and 30-2 are connected in parallel with integral control channels 32-1 and 32-2 respectively. The outputs of the channels are applied to summers 34-1 and 34-2, respectively. The outputs of summers 34-1 and 34-2 are the control signals for fuel control circuits 22-1 and 22-2, respectively.

The torque provided on the output shafts 14-1 and 14-2 is sensed by torque sensors 36-1 and 36-2, respectively, and a signal representing the torque of each shaft is provided to summer 38. The output of summer 38 is a signal, Δ torque, which represents the torque difference or imbalance between the shafts. The output of summer 38 is coupled to the system through switch 40 which is normally closed when both engines are operating. The torque difference signal from summer 38 is of one polarity or sense and is applied to proportional control 30-1 and integral control 32-1 through scale factor 42-1. The torque difference signal of the opposite polarity or sense, as provided by an inverting amplifier 44 is applied to proportional control 30-2 and to integral control 32-2 through scale factor 42-2. If scale factors 42-1 and 42-2 are equal, the signal representing the torque difference applied to proportional control channel 30-1 and integral control channel 32-1 is equal to and of opposite sense or polarity from the signal representing the torque difference applied to proportional control channel 30-2 and integral control channel 32-2. When the torque on output shaft 14-1 is equal to the torque on output shaft 14-2, the output from summer 38 and inverter 44 is zero.

The operation of proportional control chan-

nel 30-1 and integral control channel 32-1 will now be considered, it being understood that proportional control channel 30-2 and integral control channel 32-2 operate in a similar manner. Proportional control channel 30-1 includes a summer 46-1 and proportional control multiplexer 48-1 which acts as an active gain and compensation circuit. The signals Δ speed for op amp 49-1 and Δ torque from summer 38 are applied as inputs to proportional control multiplier 48-1 through summer 46-1. The output of proportional control multiplexer 48-1 is applied to summer 34-1. The multiplier is selected in accordance with the dynamic operating conditions of the system. During steady state operation the output from proportional control multiplier 48-1 is zero. The output from proportional control multiplier 48-1 increases or decreases fuel control 22-1 through summer 34-1 in response to the transient disturbances.

Integral control channel 32-1 includes a summer 50-1 an integrator 52-1 and a K multiplier 54-1. The output from integrator 52-1 is applied to multiplier 54-1 and is a non-zero value during steady state operation. The time constant of the integrator 52-1 is selected to be sufficiently long so as not to be affected by transient disturbances. The gain of multiplier 54-1 is selected to provide an output of suitable magnitude for steady state operation.

Generally, the torque provided by engine 12-1 equals the torque provided by engine 12-2. However, this is not a requirement. For example, by the appropriate selection of scale factors 42-1 and 42-2, load sharing between the two engines may be established for any particular proportions. The proportional side would also require a scale factor to accomplish this object.

WHAT WE CLAIM IS:

1. A power plant having a plurality of engines the outputs of which are coupled together for isochronous operation, each engine providing an output torque proportional to a control signal and being controlled by a control circuit for assuring that the torque is shared between the engines, wherein the control circuit comprises: means for generating a torque difference signal proportional to any difference in the output torques between the engines; means for generating a speed error signal proportional to any difference between a selected reference speed and the actual speed of the engines; and means for combining the speed error signal with the torque difference signal to provide a control signal for each engine.

2. A power plant according to claim 1, wherein the torque is shared equally between the engines.

3. A power plant according to claim 1 or claim 2, wherein there are two engines.

4. A power plant according to claim 3, wherein the means for combining the speed error signal with the torque difference signal is effective to combine the signals in one sense to provide the control signal for the first engine; and to combine the signals in the opposite sense to provide the control signal for the second engine.

5. A power plant according to claim 4, wherein the means for combining the speed error signal with the torque difference signal to provide the control signal for the first engine and the control signal for the second engine each include: a proportional control channel for generating a signal responsive to transient differences between the torque difference signal and the speed error signal; an integral control channel coupled in parallel with the proportional control channel for generating a signal responsive to any steady state difference between the torque difference signal and the error signal; and means for summing the signals from the proportional control channel and the integral control channel to provide the respective control signal.

6. A power plant according to claim 4 or claim 5, wherein the means for generating the torque difference signal comprises: a first torque sensor for providing a signal indicative of the output torque of the first engine; a second torque sensor for providing a signal indicative of the output torque of

the second engine; and a summer coupled to the first and second sensors, the output providing the torque difference signal when the output torque of the first engine exceeds that of the second.

7. A power plant according to claim 6, further including an inverter coupled to the summer, the output of the inverter providing the torque difference signal when the output torque of the second engine exceeds that of the first.

8. A power plant according to any of claims 4 to 7, further comprising switch means coupled to the means for generating a torque difference signal, for inhibiting the torque difference signal unless both the first and second engines are operating.

9. A power plant according to any preceding claim, wherein the engines are gas turbine engines and the means for controlling each of the engines in accordance with the control signal therefor is a fuel control circuit for each engine.

10. A power plant having two engines the outputs of which are coupled together for isochronous operation, having a control circuit substantially as particularly described herein with reference to the drawing.

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