# United States Patent [19]

**Jones et al.**

[11] **3,749,048**

[45] **July 31, 1973**


[54] **SIGNAL DIVIDER FOR SPEED CONTROL OF DIRECT REVERSING GAS TURBINE**


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[73] Assignee: **General Electric Company,** Schenectady, N.Y.



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[52] **U.S. Cl.** .................. **115/34 R,** 60/39.16, 416/30

[51] **Int. Cl.** .................................................. **B63h 21/20**

[58] **Field of Search** ............................ 115/34 R, 35; 60/39.16; 137/50; 415/153; 416/30


[56] **References Cited**

UNITED STATES PATENTS


| | | | |
|---|---|---|---|
| 2,912,824 | 11/1959 | Van Nest | 60/39.16 |
| 3,286,983 | 11/1966 | Scheper | 415/153 |
| 3,392,696 | 7/1968 | Buckley | 115/34 |
| 3,422,831 | 1/1969 | Straney | 137/50 |
| 3,639,076 | 2/1972 | Rowen | 416/30 |

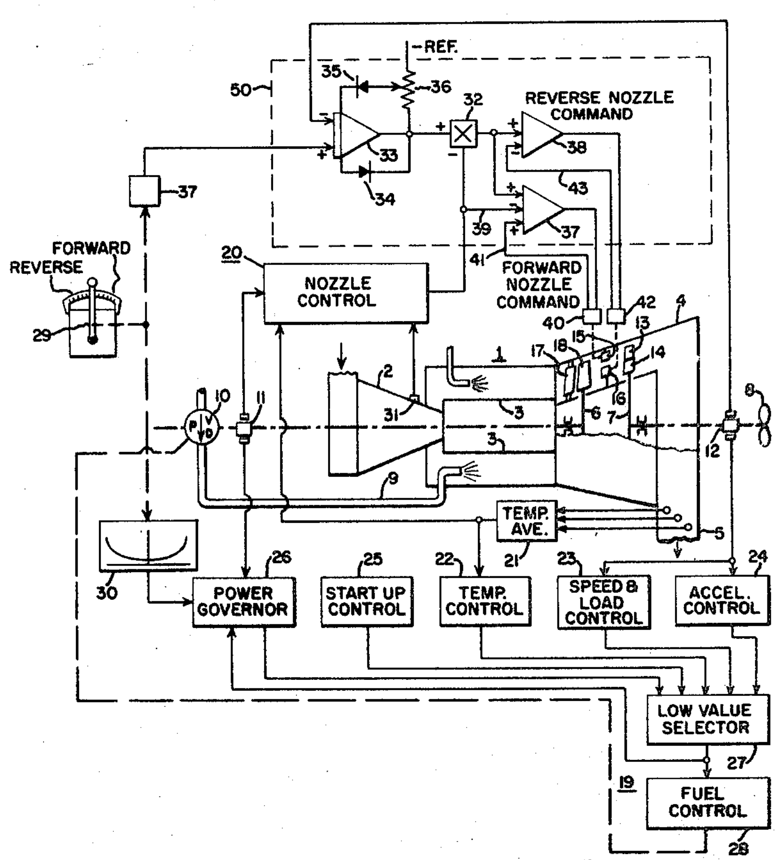


*Primary Examiner*—Milton Buchler
*Assistant Examiner*—Carl A. Rutledge
*Attorney*—William C. Crutcher et al.


[57] **ABSTRACT**


A speed control for a direct reversing gas turbine of the type adapted to separately control the flow of motive fluid through two sets of individually adjustable nozzles into forward and reversing blades on the load turbine. A nozzle control derives a command signal for total nozzle flow area from various operating conditions of the gas turbine. The command signal is split into ahead and astern nozzle command signals in a ratio which is determined by comparing propulsion lever position and propeller speed. The system maintains the desired total nozzle opening from the nozzle control, as well as the desired ratio between ahead and astern nozzle opening.


**5 Claims, 2 Drawing Figures**



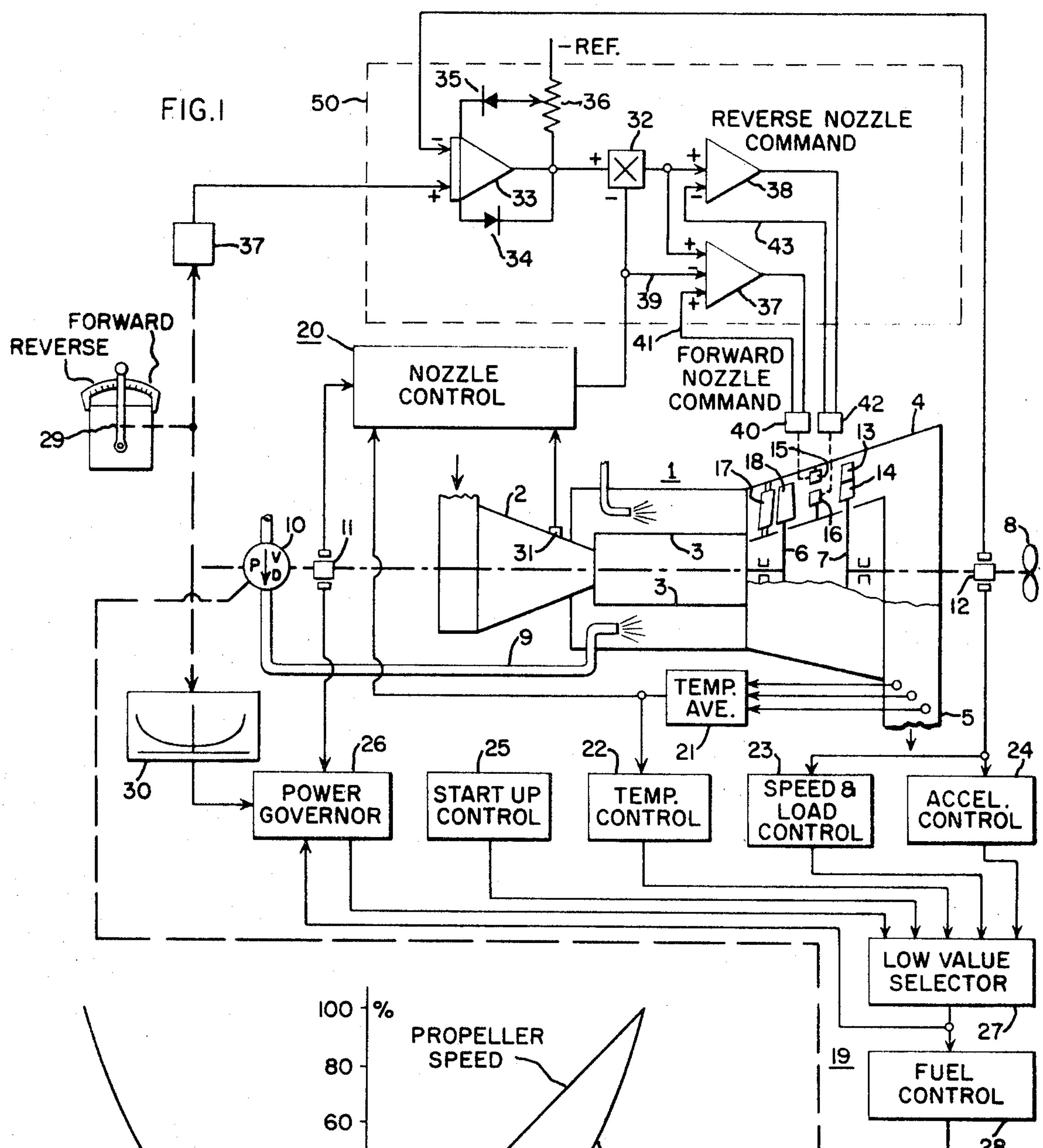

-REF.
35
36
50
32
REVERSE NOZZLE COMMAND
33
38
37
34
43
39
37
FORWARD
REVERSE
20
41
NOZZLE CONTROL
FORWARD NOZZLE COMMAND
42
4
29
40
13
15
17
18
1
14
2
16
10
11
8
31
3
6
7
3
12
9
TEMP. AVE.
5
21
26
25
22
23
24
30
POWER GOVERNOR
START UP CONTROL
TEMP. CONTROL
SPEED & LOAD CONTROL
ACCEL. CONTROL
LOW VALUE SELECTOR
27
19
FUEL CONTROL
28

FIG.1

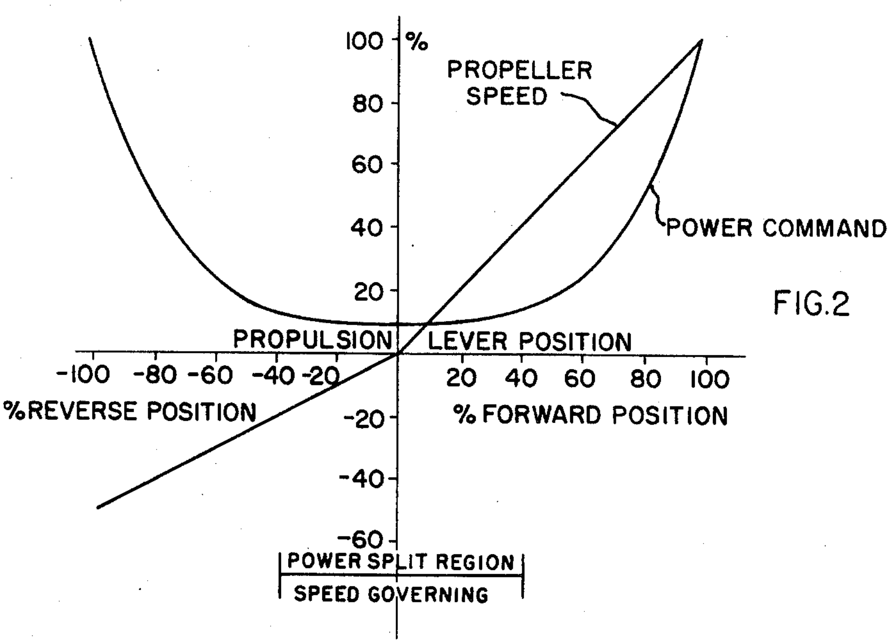

100
%
80
60
40
20
PROPELLER SPEED
POWER COMMAND
PROPULSION LEVER POSITION
-100 -80 -60 -40 -20
20 40 60 80 100
%REVERSE POSITION
% FORWARD POSITION
-20
-40
-60
POWER SPLIT REGION
SPEED GOVERNING

FIG.2

# SIGNAL DIVIDER FOR SPEED CONTROL OF DIRECT REVERSING GAS TURBINE

## BACKGROUND OF THE INVENTION

This invention was made under contract with the United States Government under Contract 0-35510 with the United States Maritime Administration of the Department of Commerce. The U.S. Government is licensed in accordance with the terms of the aforesaid contract and has reserved the rights set forth in Section 1 (f) and 1 (g) of the Oct. 10, 1963 Presidential Statement of Government Patent Policy.

The invention relates generally to a speed control for a direct reversing gas turbine, and more particularly to a control for a marine propulsion turbine driving a fixed pitch propeller which is adapted to reverse the direction of the propeller under speed control by means of separately adjustable nozzle blades.

Control systems for marine gas turbines are known, wherein reversing is accomplished through a reversible pitch propeller and means for adjusting the propeller pitch are incorporated into the control system. An example is found in U.S. Pat. No. 3,639,076 issued Feb. 1, 1972 to W. I. Rowen and U.S. Pat. No. 2,912,824 issued Nov. 17, 1959 to F. H. Van Nest et al., both of these patents being assigned to the present assignee.

In order to reduce the complications of a reversible pitch propeller, suggestions have been made for a direct reversing gas turbine, with both forward and reversing blade sections, with the gas flow leading to the separate blade sections controlled by sets of separately adjustable nozzles. Such an arrangement is shown in U.S. Pat. No. 3,286,983 issued Nov. 22, 1966 to G. W. Scheper, Jr., and assigned to the present assignee. The direct reversing gas turbine permits the flow through the forward blade sections to be controlled when the astern nozzle blades are fully closed, or conversely permits control of gas through the reversing blade sections when the forward nozzle partitions are closed. However, it will be apparent that this will greatly reduce the total effective nozzle area in the low speed ranges when the controlling nozzles are almost closed. It is desirable to reverse the turbine without restricting the gas flow through the machine.

Marine propulsion systems using steam turbines have long used reversing turbine blade sections to reverse the direction of rotation of the propeller. For example, U.S. Pat. No. 3,392,696 issued to L. P. Buckley, Jr., et al., on July 16, 1968 showed application of "bursts" astern or reversing steam in response to a difference between power response of the propulsion unit and the selected reference power response. Forward and reversing steam may also be applied simultaneously over the lower ranges as suggested in U.S. Pat. No. 3,422,831 issued Jan. 21, 1969 to K. O. Straney, et al., both of the foregoing patents being assigned to the present assignee. However, the techniques used in controlling the steam turbines are not applicable uniformly to gas turbines because of the higher temperatures and the fact that motive fluid cannot be "bottled up" in a gas turbine as it can in a steam boiler.

In a direct reversing gas turbine, it may not only be desirable to separately control the forward and reversing adjustable nozzle sections to maintain the total gas flow through the turbine, but it may further be necessary to vary the total flow in accordance with some other set of operating conditions of the gas turbine. For



example, U.S. Pat. No. 3,638,422 issued Feb. 1, 1972 to A. Loft, et al., shows a two-shaft gas turbine control system for setting the total flow through the adjustable nozzle in accordance with a number of operating conditions such as compressor speed and exhaust temperature, so as to satisfy other requirements on the gas turbine, such as a temperature limitation. It would be desirable to continue to obtain the benefits of the system which enables variations in total gas flow through a nozzle control while at the same time permitting a reversing gas turbine speed control.

Accordingly, one object of the present invention is to provide an improved control system for a direct reversing gas turbine which splits a command signal for total motive fluid flow into forward and reverse nozzle command signals.

Another object of the invention is to provide a reversing turbine control system which sets the ratio between ahead and astern nozzle command signals so as to control speed in accordance with a speed setting despite other requirements for flow of total motive fluid through the turbine.

## SUMMARY OF THE INVENTION

Briefly stated, the invention comprises a control system which accepts a first command signal for total nozzle flow area from a separate nozzle control system and a second signal representing the integrated error between a desired propeller speed represented by propulsion lever setting and actual propeller speed. The total nozzle command signal is applied to a "forward" nozzle controller. A fraction of the total nozzle command signal is obtained, as determined by the second speed error signal, and applied with subtractive effect to the ahead nozzle controller. The fractional signal is also applied at the same time to a "reverse" nozzle controller.

## DRAWING

Other objects and advantages of the invention will become apparent from the following description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a simplified schematic view of a marine direct reversing gas turbine with its control system, and

FIG. 2 is a graph of propulsion lever characteristics for the direct reversing turbine driving a ship with fixed pitch propeller.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawing, a gas turbine, shown generally as 1, has a compressor 2, combustion chambers 3, and a turbine section 4 feeding exhaust gas through exhaust stack 5. Turbine section 4 includes two separate shafts, one attached to a turbine wheel 6 which drives compressor 2 and the other attached to a load turbine wheel 7 which drives the load such as propeller 8.

Fuel is pumped to the combustion chambers 3 through fuel lines 9 by a variable delivery pump 10 driven by the compressor shaft. The rate of fuel flow depends both upon the speed of the shaft and the stroke setting of pump 10. A speed sensor 11 on the compressor shaft and a similar sensor 12 on the load turbine shaft provides the means for obtaining speed signals for the separate shafts.

The load turbine wheel 7 carries a set of blades especially adapted to accomplish reversal of the load turbine. The blades are formed with an outer "forward" blade section **13** and an inner "reversing" blade section **14.** A circumferential row of outer adjustable nozzle blades **15** control flow of fluid through the forward blade sections **13,** while an inner circumferential row of adjustable blades **16** control the flow of reversing motive fluid through the reversing blades **14.** The arrangement shown is schematic only, but a suitable construction is shown in the aforementioned U.S. Pat. No. 3,286,982.

Stationary nozzle blades **17** and turbine blades **18** for the compressor turbine may be conventional.

As in previously known two-shaft gas turbine control systems, the total energy delivered to both of the turbine wheels **6, 7** is determined by controlling the flow of fuel to the combustion chambers **3.** This is carried out by means of a fuel control system shown generally at **19.** The total energy released in the combustion chambers is divided between the two turbine shafts as determined by the nozzle control shown generally at **20.**

The fuel control **19** and the nozzle control **20** are indicated in very simple schematic form, since other types of fuel and nozzle controls than the ones shown would be suitable for carrying out the present invention. However for purposes of illustration, a typical example of these controls **19, 20,** which may be found by reference to the aforementioned U.S. Pat. Nos. 3,638,422 and 3,639,076, is described briefly below.

An average exhaust temperature is obtained by device **21** and furnished to a temperature control unit **22** in the fuel control and also to the nozzle control **20.** A speed and load control **23** and an acceleration control **24** receive load turbine speed signals from sensor **12.** A start-up control unit **25** develops a schedule of fuel flows for starting the turbine. A power governor unit **26** develops a fuel flow signal in accordance with a desired power output. All of the fuel flow signals from units **22–26** are supplied to a low value selecting device **27** which picks the lowest rate of fuel flow and, through a fuel control unit servo **28,** sets the stroke of the variable delivery pump **10.**

The selection of the reference signal to the power governor unit **26** is determined by the position of a remote manual control lever **29** which is applied to a electronic cubic function generator **30,** which is designed to provide a linear relationship between hand lever position and actual ship's speed. The actual fuel flow rate is determined in power governor **26** by a multiplying device which utilizes a signal from the shaft speed sensor **11** and the selected fuel flow signal coming from low value selector **27.**

It remains to note that the nozzle control **20** receives other signals representing operating conditions of the gas turbine such as compressor discharge pressure from a transducer **31** and a compressor shaft speed signal from sensor **11.** For example in one type of nozzle control, which is not necessary for practicing the present invention, the total nozzle command signal is used to hold the compressor speed constant. The actual compressor speed (sensor **11**) is compared to a set point which is altered as necessary by variations in other operating conditions such as exhaust temperature and compressor discharge pressure.



In accordance with the present invention, a signal divider for speed control of the reversing gas turbine is indicated generally within box **50.** A first signal from the nozzle control **20** is applied to a multiplier **32.** A second signal is applied to multiplier **32** from an integrating amplifier **33** having a diode **34** connected to prevent the output signal from becoming negative. A second diode **35** is connected to the tap of an adjustable potentiometer **36** which, in turn, is connected between a negative potential source and the output of amplifier **33.**

The position of the propulsion lever **29** is converted by a high gain device **37** to a signal proportional to position of the lever. An input signal of either polarity from device **37** is then applied to amplifier **33.** A second input to amplifier **33** of opposite polarity and indicative of actual speed of the propeller shaft is obtained from speed sensor **12.**

The first and second signal applied to multiplier **32** are multiplied by one another in such a way that the signal obtained from multiplier **32** is a fractional part of the first signal applied thereto. The fraction is between the values of **0** and **1** in proportion to the magnitude of the second signal applied thereto. Such multipliers are commercially available, a suitable device being a "quarter-squared" multiplier, available from the General Electric Company as Directo-Matic II, part .

The output from multiplier **32** is applied to a first summing amplifier **38** which provides a "reverse" nozzle command signal, and to a second summing amplifier **37** which when subtracted from a first command signal from the nozzle control, **20** representing desired total area, provides a "forward" nozzle command signal.

The forward nozzle command signal is applied to a positioning servomechanism **40** which adjusts the position of the forward adjustable nozzle blades **15.** A feedback signal representing the forward nozzle blade positions is supplied back to the input of amplifier **37** through line **41.** Similarly, the reverse nozzle command signal from amplifier **38** is supplied to a positioning servo-mechanism **42** which sets the openings of the reverse nozzle blades **16** and their actual position is fed back to the input of amplifier **38** via a line **43.**

FIG. 2 is a graph showing the variations in the power command signal going to the power governor **26** for a given position of the propulsion lever **29,** the curved characteristic being obtained from the cubic function generator **30.** The graph also shows the propeller speed which would result under ideal conditions if the power delivered to the propeller is in accordance with the power command signal. The present invention providing for a division of the motive fluid between forward and reversing blade sections takes place in a range of propulsion hand lever positions on the order of **40** percent of the full ahead or astern lever range. In this range, the invention provides for a substantially linear variation of propeller speed with respect to propulsion lever position, while the lever simultaneously sets the total gas turbine available power through a fuel flow command signal.

## OPERATION

The operation of the invention will be understood from the following description. In any given position of the propulsion lever within the power split region indicated on FIG. **2,** a given fuel flow to the combustion chambers is dictated by the power governor unit **26.** However the additional fuel control units **22–24** can override the specified fuel flow by reducing it via the low value selector **27.** Total power available to the compressor and to the load turbine is therefore determined by this fuel flow command.

The nozzle control **20** provides a total nozzle command signal which sets the combined effective flow area through the separate forward and reversing nozzle blades **15, 16.** This total flow is largely determined by the speed of the compressor and has a marked effect on the turbine exhaust temperature. The nozzle control exemplified here happens to function so as to hold the compressor speed at a set point which is determined jointly by the exhaust temperature and the compressor discharge pressure. However, any type of nozzle control which gives a command signal for total nozzle flow is suitable for this invention. Accordingly, the total nozzle command signal from nozzle control **20** will vary in accordance with operating conditions of the gas turbine.

It will be understood that when the total flow is directed through both the forward and reversing turbine blade sections at the same time, reverse torques from the two blade sections will be created which affect the speed, since only the net torque turns the shaft or load wheel **7.** For example if the flows through blade sections **13, 14** were such as to create equal and opposite torques on the load wheel **7,** it would not turn at all, and yet flow would be maintained through the gas turbine just as though the load wheel were generating power in a conventional sense.

The fraction of the total nozzle command signal which is used to split the flow between forward and reverse blade sections is determined by deviations between desired speed, as set by the propulsion lever **29,** and actual propeller speed, as sensed by speed sensor **12.** These equal and opposite signals are applied to the integrating amplifier **33** and the integrated error signal therefrom is applied to multiplier **32.** The output from multiplier **32** is a fraction of the total nozzle command signal. This fractional signal is used as an input to the reverse nozzle amplifier **38** to set the opening of the reverse adjustable nozzle blades **16.** The balance of the total nozzle command signal is obtained from the forward nozzle command amplifier **37** and used to set forward adjustable nozzle blades **15.** This balance is obtained in amplifier **37** by subtracting the fractional signal from the total signal supplied by nozzle control **20.**

Deviations between desired propeller speed and actual speed continuously adjust the fractional part of the total nozzle command signal which is used to divide the flow between ahead and astern nozzles. The speed change response is good, the only significant inertial elements being the load turbine wheel and the propeller shafting. The nozzle control **20** is "unaware" of the propeller speed, except perhaps through variations in exhaust temperature. It functions in its normal way to keep the exhaust temperature under control by generating new total nozzle command signals so as to vary the power supplied to (and therefore the speed of) the compressor.

Thus there has been described an improved control system for a two-shaft gas turbine of the direct reversing type. Although the description has been exemplified as a marine propulsion turbine, it will be apparent that the invention can be used equally well with any kind of gas turbine driven device which requires a reversible speed control.

While there has been decribed what is considered to be the preferred embodiment of the invention, other modifications will occur to those skilled in the art and it is desired to secure in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

**1.** In a two shaft direct-reversing gas turbine having a load turbine shaft with forward and reversing blade sections and having forward and reversing nozzle blades for separately and respectively controlling flow therethrough, a control system comprising:

means for controlling flow of fuel to said gas turbine in accordance with a selected power setting,

a nozzle control providing a first nozzle command signal in response to selected operating conditions of the gas turbine for dividing available power between the gas turbine shafts and representing a desired total nozzle opening of both forward and reverse nozzle blades,

means for providing a second signal representing a deviation between a desired load shaft speed and actual load shaft speed,

means for dividing said first signal into a forward nozzle command signal and a reverse nozzle command signal in proportions determined by said second signal, and

a plurality of positioning servomechanisms setting the positions of said forward and reversing adjustable nozzle blades in accordance with said forward and reverse command signals respectively.

**2.** The combination according to claim **1,** wherein said dividing means comprises:

A multiplier for obtaining a fractional signal which is equal to the first signal multiplied by a fraction between 0 and 1, which fraction is proportional to the second signal,

A first summing amplifier connected to receive said fractional signal and to supply the reverse nozzle command signal, and

A second amplifier connected to receive said first signal and said fractional signal and to supply the difference therebetween as the forward nozzle command signal.

**3.** The combination according to claim **1,** wherein said means providing said second signal comprises an integrating summing amplifier connected to receive a load shaft speed command signal and an actual load shaft speed signal and to supply the time integral of the difference therebetween as said second signal.

**4.** The combination according to claim **1,** including a manual control lever and wherein said selected power setting for said fuel flow control means and said load shaft speed command signal are both obtained from the position of said lever.

**5.** The combination according to claim **4,** wherein said load shaft drives a propellor of a vessel and wherein said control lever is a remote propulsion lever for setting both gas turbine power and propeller speed simultaneously.

* * * * *