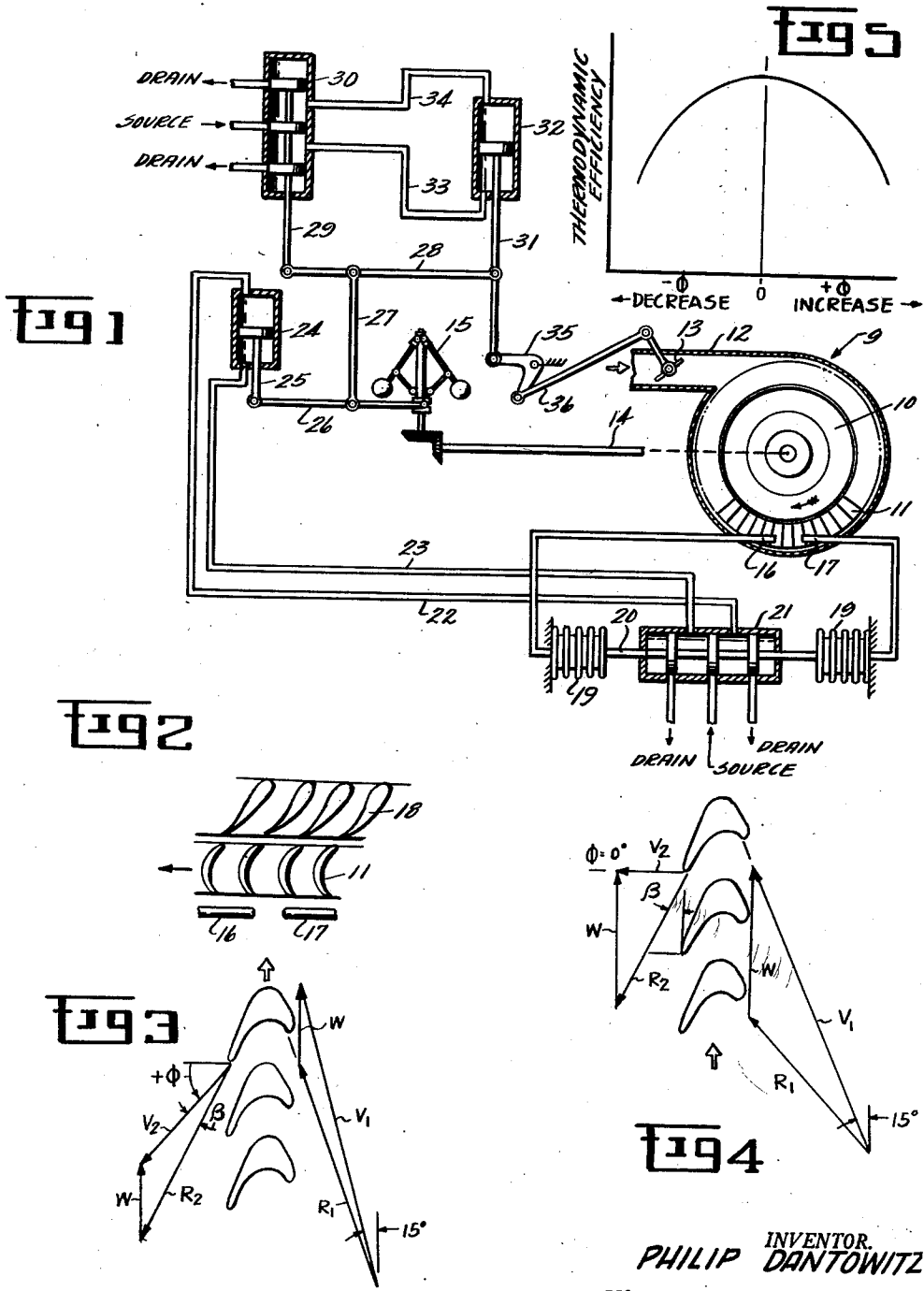


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TURBINE SPEED CONTROL
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TURBINE SPEED CONTROL

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2 Claims. (Cl. 253—59)

The present invention relates to a turbine speed control and more particularly to means for maintaining a turbine at its most efficient speed.

In aircraft installations where small turbines are used to drive accessories for the aircraft, efficiency is important because increased efficiency in these machines will result in reduced fuel requirement thus extending the range of the airplane. It is well-known by those skilled in the art that for a given temperature and pressure of motive fluid at the turbine inlet, a turbine will operate most efficiently thermodynamically, that is extract the greatest portion of the energy available in the motive fluid supplied thereto when running at a particular speed. It is also well-known by those skilled in the art that the speed at which maximum thermodynamic efficiency occurs corresponds to that at which motive fluid leaves the turbine rotor at a definite angle which is unique for a particular turbine design but which is not a function of turbine inlet conditions. Although there are some loads which must be driven at a particular speed regardless of efficiency there are many which need not, and it is in cases where constant speed is not required that the present invention has application. Accordingly, it is an object of the invention to provide an improved control for a turbomachine with a variable speed load which provides efficient turbine operation.

Another object of the invention is to provide an improved speed control means for a turbine which maintains the turbine at its most efficient speed.

Briefly, these and other objects of the invention are obtained by sensing the direction of the motive fluid leaving the turbine rotor and adjusting the speed of the rotor in accordance therewith.

The invention will be better understood from the following description taken in connection with the accompanying drawing in which:

Fig. 1 is a diagrammatic illustration of one embodiment of the invention as applied to an axial flow turbine;

Fig. 2 is an end view of the blading disclosed in Fig. 1;

Fig. 3 is a schematic velocity diagram of motive fluid flow through the bucket passageways with the turbine rotating at a speed below its most efficient speed;

Fig. 4 is a diagrammatic view similar to Fig. 3 depicting motive fluid flow when the turbine is operating at its most efficient speed; and

Fig. 5 is a graphical representation of the thermodynamic efficiency plotted against the angle of the gases leaving the bucket rotor for a typical turbine.

In the drawing, a turbine is disclosed generally at 9 comprising a rotor 10 having turbine buckets 11 mounted thereon and an inlet duct 12 for motive fluid in which is mounted a throttling valve shown in the drawing as a butterfly valve 13. In the arrangement shown, the speed of the turbine rotor 10 is regulated by the opening of the butterfly valve 13. It will be understood by those skilled in the art that in place of the butterfly valve 13, other means may be employed such as a variable area turbine

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nozzle diaphragm or a movable control plate may be used to control the flow of motive fluid which passes through the turbine blades 11. Any of these common means of control may be employed in practicing the invention.

Connected either integrally or through spline means to the turbine rotor 10 is a shaft 14. The shaft 14 is connected through bevel gearing to drive a conventional fly-weight speed governor 15. A pair of Pitot tubes 16 and 17 are positioned in the turbine casing immediately downstream from the turbine buckets 11 so as to sense the velocity of the motive fluid leaving the turbine buckets. This arrangement can be best seen in Fig. 2 in which nozzle partitions 18 form a turbine nozzle diaphragm through which motive fluid flows after entering the turbine through an inlet 12.

Referring again to Fig. 1, the Pitot tubes 16 and 17 are connected to a pair of bellows 19, the bellows being of any conventional design. The bellows 19 are mechanically connected to opposite ends of a control stem 20 for a conventional fluid pilot valve 21. Fluid communication is supplied between the pilot valve 21 and a piston actuator 24 by two fluid conduits 22 and 23. An output shaft 25 of the piston actuator 24 is pivotally connected at one end to a linkage member 26. The linkage member 26 is pivotally connected at the other end to the fly-weight governor 15 and pivotally connected at a point between its ends to one end of a connecting link 27. The other end of the connecting link 27 is in turn pivotally connected to another linkage member 28 which is pivotally connected at one end to a control shaft 29 for a pilot valve 30 and at the other end pivotally connected to the output shaft 31 of a piston actuator 32. Fluid communication is provided between the pilot valve 30 and piston actuator 32 through fluid conduits 33 and 34. The output shaft 31 of the piston actuator 32 is also connected to a pair of linkage members 35 and 36 which control the opening of the butterfly valve 13.

The velocity diagrams in Figs. 3 and 4 illustrate schematically the flow of motive fluid through the turbine buckets and show the effect of turbine rotor speed on the direction of gases leaving the turbine buckets. In these figures V1 represents the absolute velocity of the entering motive fluid as it leaves the turbine nozzles and R1 represents the relative velocity of the entering motive fluid with respect to the rotor. W represents the linear speed of the turbine rotor at the bucket pitch line. R2 represents the relative leaving velocity of the motive fluid and V2 represents the absolute motive fluid leaving velocity. In Fig. 3 the turbine rotor velocity is relatively small and it will be seen that the angle ϕ between the absolute leaving velocity V2 and a line normal to the direction of rotation is relative large. In Fig. 4, the turbine rotor speed is greater so that with the same direction and magnitude of absolute entering velocity of the motive fluid V1, the absolute leaving velocity V2 is smaller and also leaves the buckets in an axial direction. In this case the angle ϕ is equal to zero. Should the turbine rotor speed be increased to a still greater value, the angle ϕ would increase in a negative direction and the magnitude of V2 would again increase. It is well known to those skilled in the turbine art that the portion of energy contained in the motive fluid entering the bucket rotor that is imparted to the rotor 10, which is defined as thermodynamic efficiency, may be determined as a function of the angle ϕ which is commonly known as the "swirl angle." Fig. 5 indicates a representative plot of thermodynamic efficiency versus swirl angle, ϕ , for a typical turbomachine. The values for thermodynamic efficiency are not indicated along the ordinant of the curve inasmuch as the particular values vary for each design configuration. In most turbines, maximum thermodynamic efficiency will occur when

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the gases leaving the turbine rotor depart therefrom in a nearly axial direction that is with no tangential component. Thus, for purposes of illustration, it will be assumed that the turbine used has an efficiency peak which corresponds to $\phi=0$ as shown in Fig. 5. The exact angle at which maximum efficiency occurs for a given turbine design may be determined easily from conventional efficiency tests.

Referring to Figs. 1 and 2 again, it can be seen that the Pitot tubes 16 and 17 are arranged so that only when the motive fluid leaving the rotor 10 leaves in an axial direction will the pressures sensed by the tubes 16 and 17 be equal. Whenever motive fluid leaves the rotor 10 with a tangential component, the impact total pressure sensed by one of the Pitot tubes will be greater than that sensed by the other. The Pitot tubes are positioned to measure any variation in the swirl angle from a zero value. It is the purpose of the bellows arrangement in connection with the pilot valve 21 and actuator 24 to reset the referenced speed maintained by the speed governor 15 so that the turbine at all times operates at a speed corresponding to zero swirl angle to obtain maximum thermodynamic efficiency.

The Pitot tubes are shown and described herein as being oriented to detect any variation in direction in which the gases leave the rotor from an axial direction (zero swirl angle) as it is assumed that the turbine in the present instance has an efficiency versus swirl angle characteristic corresponding to that shown in Fig. 5. Since this characteristic may vary depending on the design parameters of the turbomachine being used so that the efficiency peaks at a value of ϕ other than zero, it should be understood that the Pitot tubes may be shifted from the position illustrated in order to sense a variation from any desired swirl angle. It will be obvious to those skilled in the art that the Pitot tubes should be oriented to sense in a line normal to the desired direction of the desired leaving angle for the motive fluid so as to, in connection with the bellows arrangement, sense any variation in the direction of the leaving motive fluid from that desired.

The operation of the apparatus thus described may be described with more particularity as follows. Assume that the turbine is driving a load and running at its maximum thermodynamic efficiency. Now assume that as a result of a change in inlet temperature of the motive fluid supplied to the turbine at 12, the inlet velocity V1 of motive fluid should increase greatly. Under these circumstances the velocity V1 will be great with respect to the speed of the rotor W so that the corresponding velocity diagram will resemble that shown in Fig. 3. Under these circumstances the swirl angle ϕ will be relatively large in a positive direction so that the impact pressure sensed by the Pitot tube 17 will exceed by a fairly large amount that sensed by Pitot tube 16. The differential in pressure sensed by the Pitot tubes 16 and 17 will result in an unbalance in forces being applied to the pilot valve control stem 20 by the bellows 18 and 19 resulting in the control valve stem moving to the left as shown in Fig. 1. Motion of the pilot valve stem 20 to the left in this fashion will cause pressurized hydraulic fluid to be supplied to the fluid conduit 23 and at the same time force the conduit 23 to drain. The resulting unbalance in fluid pressure across the piston of the piston actuator 24 will result in a downward motion of the piston actuator output shaft 25 thus resetting the speed that will be maintained by the flyweight governor 15. The flyweight governor 15 controls the speed of the turbine by controlling the position of the pilot valve 30 through linkages 26 and 27 and the pilot control stem

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29. The basic speed control system including the speed governor 15, pilot valve 30, and piston actuator 32 is a common one and the position of the throttling valve 13 is fed back through the control linkage 28 to provide stabilization through the control. When a new desired speed is set by the piston actuator 25 by moving downward as we have just seen the pilot stem 29 is pulled downward so that the flyball governor must move the link 26 upward to restore the system to balance. As the speed of the turbine increases as a result of the downward motion imparted to the main control pilot valve 30 by the motive fluid direction sensing arrangement including the Pitot tubes 16 and 17, the flyweights of the flyweight governor 15 moves radially outward so that an upward motion is imparted to the control linkage 26 from the governor, resulting in an upward motion of the control stem 29 of the pilot piston 30, thus restoring the pilot valve to its neutral position as shown in the drawing at some higher speed as determined by the position of the piston actuator 24.

While a particular embodiment of the invention has been illustrated and described, it will be obvious to those familiar with the art that various changes and modifications may be made without departing from the invention and it is intended to cover in the appended claims all such changes and modifications that come within the true spirit and scope of the invention.

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

1. The combination of a turbomachine having an axial flow bladed rotor, a pair of total pressure sensing devices mounted adjacent said rotor and operably connected to sense the variation of velocity of motive fluid leaving said rotor from a predetermined direction, valve means for controlling the flow of motive fluid to said turbine, speed control means operably connected to said valve means to regulate said valve means to maintain the speed of said turbomachine at a selected value, and speed selecting means interconnecting said pressure sensing devices and said speed control means whereby said speed selecting means operate through said speed control means to maintain said turbomachine at a speed which results in a zero variation of the velocity of motive fluid leaving said rotor from said predetermined direction.

2. The combination of a turbomachine having a bladed axial-flow turbine rotor, fluid pressure sensing means arranged adjacent a motive fluid exhaust portion of said rotor to produce a signal proportional to the tangential component of velocity of the motor fluid leaving said rotor, speed control means operated by and in response to the speed of said turbomachine for regulating the speed thereof at a selected reference level, means for adjusting said speed reference level, and means interconnecting said speed reference adjusting means and said pressure sensing means to vary said speed reference level as a function of said signal.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,816,731

December 17, 1957

Philip Dantowitz

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 43, for "having" read -- leaving --.

Signed and sealed this 25th day of February 1958.

(SEAL)

Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON
Commissioner of Patents