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2,355,177

REGULATION OF FREE PISTON TURBO-GENERATOR SYSTEMS

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2 Sheets-Sheet 1

Fig. 1.

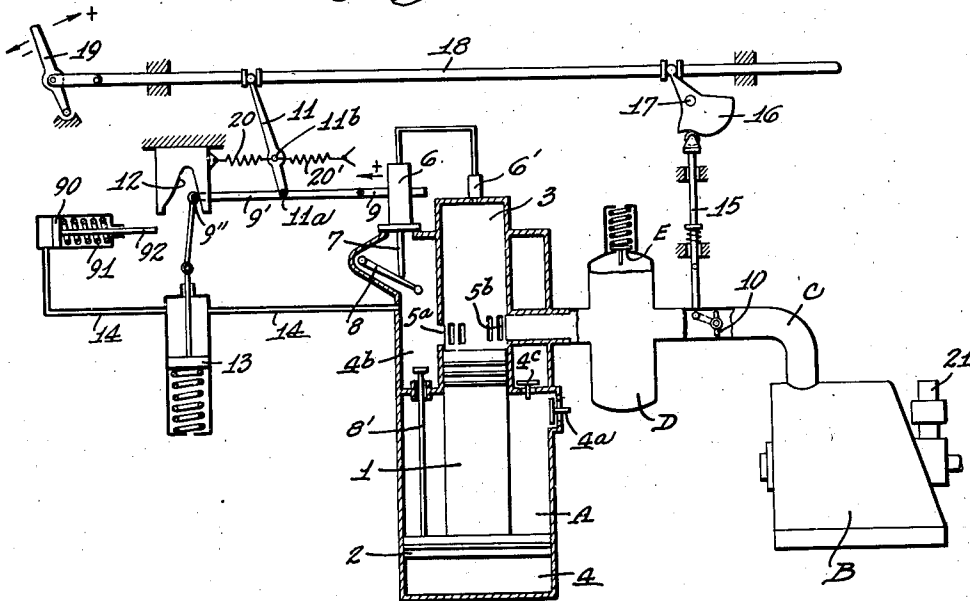
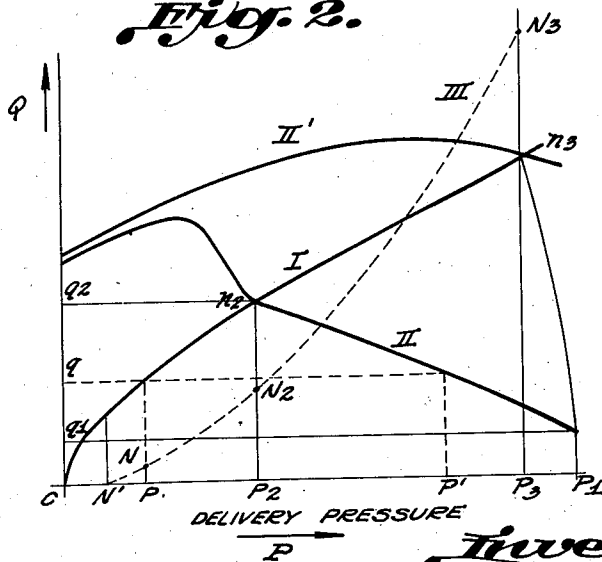


Fig. 2.



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2 Sheets-Sheet 2

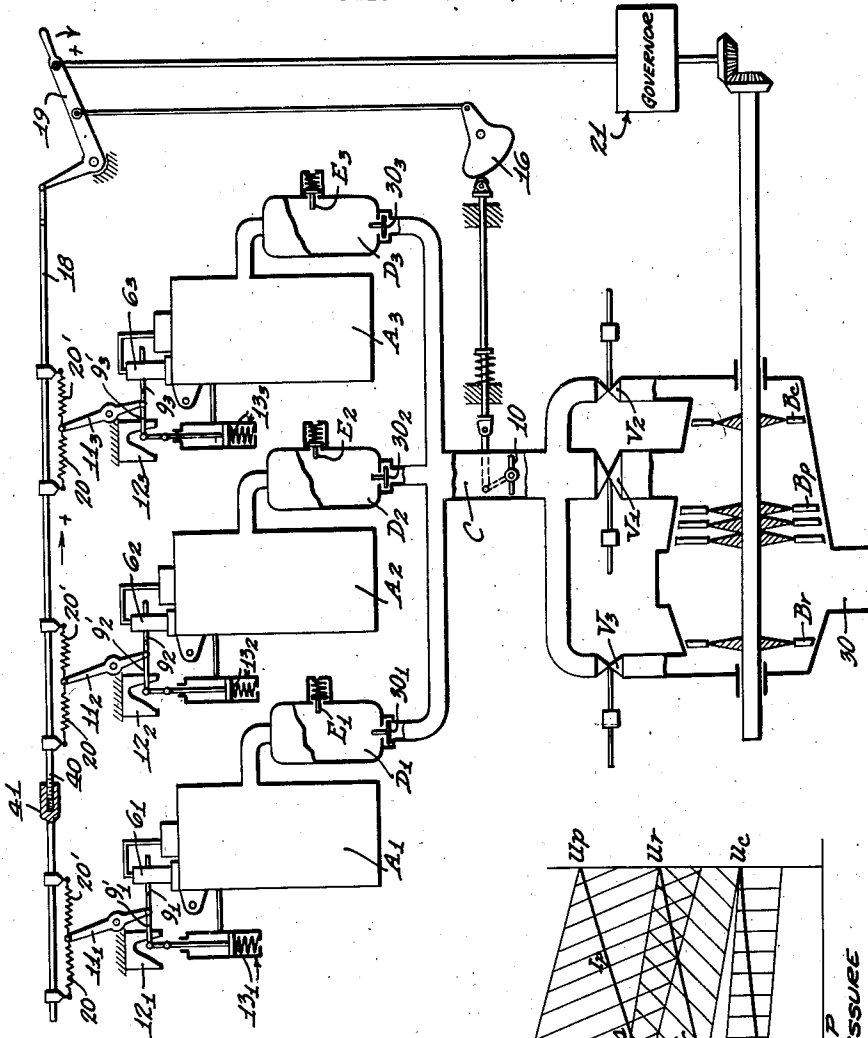
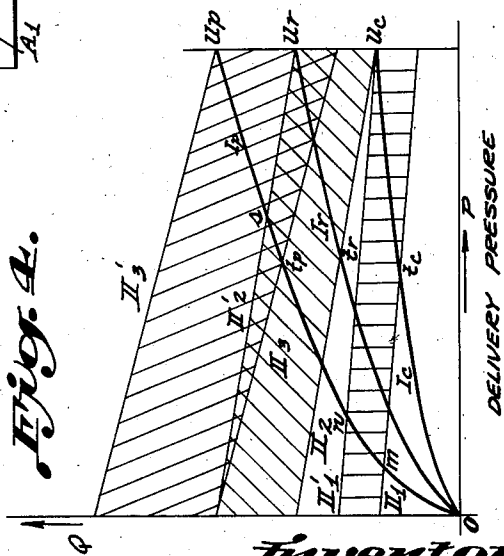


Fig. 3.

Fig. 4.



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UNITED STATES PATENT OFFICE

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REGULATION OF FREE PISTON TURBO-GENERATOR SYSTEMS

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3 Claims. (Cl. 60—13)

The present invention relates to the regulation of free piston turbo-generator systems, that is to say systems including at least one gas turbine fed with compressed gas by one or several free piston generators.

As it is known, a free piston generator includes at least one mechanical unit freely movable in a cylinder and including at least one compressor piston for providing the compressed air necessary for the scavenging and the feed of the portion of said cylinder in which combustion takes place. The gaseous mixture under pressure which leaves this cylinder and which comprises the excess of scavenging air mixed with the combustion products is fed to the turbine for supplying mechanical work, by expansion there-

The object of the present invention is to provide a system of this type which is better adapted to meet the requirements of practice and in particular in which the regulating means are simpler and more efficient.

With this object in view, according to an essential feature of the present invention, the system, which includes means for controlling the amount of fuel fed to the generator or generators for regulating the rate of delivery and the pressure of the motor gases within a certain zone of working of the turbine, further includes means for acting upon the pressure of the motor gases, by throttling of the passage through which they flow, within another zone of working of the system.

According to another feature of the invention, I combine, in a single control member, the means for adjusting the amount of fuel fed to the compressor and the means for acting directly upon at least one of the characteristics, for instance the pressure of the motor gases.

Other features of the present invention will result from the following detailed description of some specific embodiments thereof.

Preferred embodiments of the present invention will be hereinafter described, with reference to the accompanying drawings given merely by way of example and in which:

Fig. 1 is a diagrammatical view of a power plant including a single gas generator and a turbine fed by said generator, together with regulating means according to one form of the invention;

Fig. 2 is a diagram showing curves of operating values for the system of Fig. 1;

Fig. 3 is a diagrammatical view showing the application of the regulating means of the in-

vention to a power plant including a plurality of generators feeding gas to a multiple unit turbine;

Fig. 4 is a diagram showing curves of operating values for the system illustrated by Fig. 3.

In the following description, the invention is applied to a system including at least one free piston generator and a gas turbine fed by said generator or generators.

In the form of Fig. 1, the power plant includes a single compressed gas generator A feeding gas under pressure to a turbine B; a conduit C interconnecting the exhaust of the generator and the intake of the turbine, with a reservoir D mounted in said conduit and fitted with a safety valve E.

The free piston generator, is of a well known type of construction. It includes at least one reciprocating mechanical unit including two pistons 1 and 2, secured to each other, piston 1 being movable in motor cylinder 3, while piston 2 is movable in compressor cylinder 4. Compressor 4 supplies compressed air for the scavenging of the motor cylinder 3. Thus air is drawn into cylinder 4 through valve 4a on the downstroke of piston 2, and exhausted into intake manifold 4b through valve 4c on the upstroke of piston 2. Cylinder 3 is provided with inlet ports 5a and exhaust ports 5b. The combustion gases mixed with the excess of the compressed air fed for the scavenging of cylinder 3 escape therefrom through ports 5b into conduit C. These gases constitute the motor fluid to be fed to turbine B. The feed of fuel into the motor cylinder is effected in any suitable manner, for example, as shown by the drawings, by a device including an injector 6' and a pump 6 controlled by rod 7 operated by a lever 8 which is actuated by a rod 8' connected to the mechanical unit formed by pistons 1 and 2 as shown, rod 8' is carried by piston 2.

The regulation of the quantity of fuel fed into cylinder 3 can be obtained through the sliding displacement of an adjustment rod 9 operated by a regulating device which will be hereinafter described.

In order fully to understand the principle of regulation of such a system, I will refer to the diagram of Fig. 2 which shows the characteristic curves of the rates of delivery plotted in ordinates, while the pressures are plotted in abscissae.

In this Fig. 2, the rates of delivery are shown: (a) As relating to the turbine by curve I; and (b) As relating to the generator by a system

of curves ranging within two limit curves, one of which, to wit curve II, corresponds to the minimum working stroke of the pistons (necessary for opening the scavenging ports of the motor cylinder), while the other, to wit curve II', corresponds to the maximum stroke which can be achieved in such a machine.

Curve I intersects curves II and II' at two points n_2 and n_3 corresponding to two different rates of delivery between which the generator can supply, by suitably determining the length of stroke of its free pistons, the amount of gas at pressure suitable for the turbine. Below point n_2 , that is to say for all pressures of admission of gases to the turbine which are lower than P_2 , the generator supplies an excess of gas that is to say the generator is working at a rate of delivery higher than that which is necessary for the feed of the turbine, but below which said generator could not work.

Finally, curve III shows the useful powers or loads of the turbine as a function of the working pressure thereof.

It follows from the preceding explanations that the regulation of the generator below point n_2 must be different from the regulation at higher pressures.

According to the invention, when, as it is generally the case, the derivative

$$\frac{dq}{dp}$$

corresponding to curve II in the zone of working below n_2 , that is to say for loads lower than N_2 , is negative, the amount of fuel supplied to the generator is regulated in such manner as to produce the amount of gas corresponding to the actual operation of the turbine, this gas having however a pressure higher than that which corresponds to curve I. This is imposed by the structure of the generator as characterized by curve II, and thus there is interposed in feed conduit C leading to the turbine a throttling member such as a valve 10, the position of which is chosen in accordance with the power to be produced.

This member 10 reduces for instance, for the desired rate of gas delivery q , the pressure p' of the gases from the generator down to a pressure p which corresponds to the rate q of the characteristic curve I of the turbine, when the latter is working with a load equal to N (curve III).

In the zone of working above point n_2 , that is to say for loads ranging from N_2 to N_3 , it suffices to act merely upon the amount of fuel injected into the motor cylinder. The regulation is effected either manually or automatically within the lower and upper limits which depend upon the working pressure of the generator and correspond to the minimum and maximum strokes, respectively, of the generator.

In the example shown by Fig. 1, rod 9, which determines the amount of fuel fed to cylinder 3, is controlled by a lever 11 pivotally connected at 11a to said rod. The displacements of rod 9 are limited by a cam 12 including two inclined surfaces adapted to cooperate with a finger 9'' carried by a rod 9' pivoted to control rod 9. The action of cam 12 must be variable in accordance with the value of the working pressure of the generator. For this reason, in the example illustrated by Fig. 1, rod 9', which carries finger 9'', is mechanically connected with a piston 13 one of

the faces of which is subjected to said working pressure, fed through conduit 14.

It will be readily understood that, with such an arrangement, it is possible, for every working pressure, to vary the amount of fuel which determines the rate of delivery of the motor gases, within two limits which are variable in accordance with the value of said working pressure.

As it results from the shape of characteristic curves II and II' shown by the diagram of Fig. 2, the shape of the inclined surfaces of cam 12 is such that the limits of abutment are closer to each other as the pressure is lower.

According to another feature of the present invention, the two regulating means 9 and 10, which act respectively for working conditions below and above n_2 , are combined together so as to be operated by a single control member operated either manually or automatically by the speed governor of the turbine.

For this purpose, supposing that throttling member 10 is controlled by a rod 15, itself operated through a cam 16 pivoting about an axis 17, the angular displacements of cam 16 and lever 11 are simultaneously effected by making use of a single rod 18. This rod 18 is operatively connected with a control member 19. Care must be taken to make lever 11 inoperative within the zone of loads for which a throttling of the gaseous stream is effected and, on the contrary, cam 16 must not work within the zone of loads for which regulation is obtained merely by quantitative variation of the fuel fed to cylinder 3.

This result can be obtained in various ways. For instance, as shown by Figure 1, lever 11 pivots about an axis 11b, carried by two opposed springs 20 and 20'. On the other hand, cam 16 is given a circular outline beyond the position for which the throttling member 10 is fully opened.

Finally I provide safety means for reducing or even stopping the feed of fuel to the motor cylinder when the point n_3 (pressure p_3) of characteristic curve I is reached. This device includes a piston 90 operated on the one hand by the working pressure of the generator and subjected on the other hand to the thrust of an opposing spring 91. Piston 90 is joined in a rod 92 which will force finger 9'' against the inclined face of cam 12 which corresponds to the minimum rate of delivery of the generator, when pressure p_3 is exceeded.

The working of the regulating system according to the invention, as above described, is the following:

After the system has been started, throttle valve 10 is first fully closed. The pressure increases in reservoir D up to a value p_1 corresponding to a rate of delivery q_1 of the generator.

If throttle valve 10 is not immediately opened, the gases fed by the generator escape to the outside through safety valve E.

For the positions of control member 10 which corresponds to a full or part closing of throttle valve 10, the tension of springs 20, 20' applies finger 9'' against the inclined face of cam 12 which corresponds, for the various pressures that may exist, to the minimum rate of delivery of the generator.

When operating member 19 is moved in the direction of the arrow marked by the positive sign, throttle valve 10 is gradually opened, while the lever 11 pivots around pivot 11a and therefore has no action whatever upon rod 9. The inlet pressure of the gases fed to the turbine increases

at the same time as the generator delivery pressure decreases.

If, for instance, the power required by turbine B is equal to N, said turbine must be fed with an amount q of gas of a pressure equal to P.

On the other hand, in order to obtain this amount q of gas from the generator, the latter must work at a pressure equal to P' as this results from the curve II of Fig. 2. Therefore, throttle valve 10 is opened in such manner as to reduce the pressure P' existing in reservoir D, down to the pressure P at which the motor gases enter turbine B. Due to the action of piston 13, the position of abutment of finger 9'' upon the inclined face of cam 12 which corresponds to the minimum stroke of pistons 1—2, varies as a function of the pressure when the latter varies between P₁ and P₂. The amount of fuel fed during this period thus ensures, for every given delivery pressure, a minimum stroke of the generator. This situation is maintained until throttle valve 10 is fully opened, which corresponds to power N₂ (Fig. 2) and pressure P₂.

For powers ranging between N₂ and N₃, finger 9'' is no longer compelled, by springs 20 and 20', to bear against that of the two inclined faces of cam 12 which corresponds to the minimum stroke, said springs now keeping the pivot point 11b of lever 11 in a substantially fixed position.

The action of lever 19 is then directly transmitted, through lever 11, to the fuel feed regulating rod 9 whereby the rate of delivery of the generator is varied within limits determined by the inclined faces, acting as abutments, of cam 12 which correspond respectively to the minimum and maximum strokes of the generator. As above explained, these abutments depend upon the action of the working pressure of the generator, said pressure being practically equal to the pressure of admission to the turbine when the throttle valve is fully opened and increasing simultaneously with the useful power.

During the whole of this regulation period, the throttle valve remains open due to the circular shape of the corresponding portion of cam 16.

I will now describe a regulating system according to the invention when there are several generators and eventually several turbines.

This form is illustrated by Fig. 3. It corresponds to the case of three generators, A₁, A₂, A₃, and three turbine elements working on the same shaft. For instance, element B₁ constitutes the main turbine, element B₂ constitutes the turbine to be used for reduced power working, and element B₃ is the turbine to be used for backward operation.

These three turbines, fed through a common conduit C, have each their distinct inlet while their outlet 30 is common to the three of them.

Valve means V₁, V₂ and V₃ permit the independent feeding of gas to the respective turbine elements.

Check valves such as 30₁, 30₂ and 30₃ are mounted between conduit C on the one hand and, the other hand, reservoirs D₁, D₂, D₃, respectively fed by generators A₁, A₂ and A₃.

In the diagrams of Fig. 4:

I_p is the characteristic curve giving the rate of flow as a function of the pressure in turbine B₁;

I_r is the characteristic curve giving the rate of flow as a function of the pressure in turbine B₂;

I₂ is the characteristic curve giving the rate of flow as a function of the pressure in turbine B₃;

II₁ and II₁' are the characteristic curves of the rate of delivery as a function of the pressure for

one generator, for the minimum stroke and the maximum stroke respectively;

II₂ and II₂' are the characteristic curves of the rate of delivery as a function of the pressure for two generators, for the minimum stroke and the maximum stroke respectively; and

II₃ and II₃' are the characteristic curves of the rate of delivery as a function of the pressure for three generators, for the minimum stroke and the maximum stroke respectively.

I will designate by the expression "throttling regulation" the regulation above described according to which the control member acts simultaneously upon the throttling member 10 and upon the means for regulating the fuel feed.

The expression "free control pump delivery regulation" designates the regulation for which, the throttling means being fully opened, the control member acts, within limits determined by the inclined surfaces of the cam, upon rods 9₁, 9₂ and 9₃ which control the fuel feed to the generators.

It results from Fig. 4 that the second mentioned regulation system is applicable:

(a) For turbine B₁, and three generators, within zone t_p-u_p ;

(b) For turbine B₁, and two generators, within zone t_r-u_r ; and

(c) For turbine B₂, and a single generator, within zone t_c-u_c .

According to the invention, it is possible to ensure proper regulation within the zones of operation of the turbines by proceeding as follows:

Similarly to what has been above explained, in the case of a single generator, each generator is fitted with its regulating system by connecting the rods 9₁, 9₂, 9₃, which determine the amount of fuel fed to each of the generators A₁, A₂, A₃, with a lever 9'₁, 9'₂, 9'₃ subjected, on the one hand, to the action of a piston 13₁, 13₂, 13₃, one of the faces of which supports the discharge pressure of the corresponding generator, and, on the other hand, to the action of a pivoting lever 11₁, 11₂, 11₃. I further provide cams 12₁, 12₂, 12₃ having two inclined surfaces acting as abutments for limiting the displacements of each of the groups 9₁—9'₁, 9₂—9'₂, 9₃—9'₃. Furthermore, I connect the free ends of levers 11₁, 11₂, 11₃ with a single rod 18 by springs 20 and 20' operated by a single control member 19. Lever 19 is operatively connected with a link system capable of controlling throttling member 10 through a cam 16 which includes, as above explained, a circular portion whereby lever 19 ceases to have any action upon member 10 after said member has been fully opened. Lever 19 may be manually operated or it may be coupled with the governor 21 of the turbine. Throttling member 10 is located in conduit C which is common to the three generators, whereby it suffices to provide a single throttling member.

Concerning now the operation at rates of delivery respectively lower than those of points t_p , t_r and t_c , the desired result is obtained by producing, in a manner similar to that above explained, a drop of pressure in the feed conduit C of the turbine through the operation of throttling member 10.

As long as this member 10 is not fully opened, pumps 6₁, 6₂ and 6₃ are working at their minimum rate as is permitted by pressure exigencies in the generators, due to the opposed action of springs 20, 20' and of the corresponding pistons 13₁, 13₂, 13₃, these spring actions causing the respective rods 9'₁, 9'₂ and 9'₃ to bear against

the inclined surfaces of cams 12₁, 12₂ and 12₃ which correspond to minimum rate of delivery.

The plant illustrated by Fig. 3 can also be used for feeding a single turbine, such for instance as turbine B_p, according to the load thereof, through one, two, or three generators. For this purpose, I provide means for varying the length of rod 18. Such means may for instance consist of a threaded part 40 carried by one section of rod 18 and cooperating with a threaded socket, 41 carried by another section of said rod.

By thus varying the length of said rod, it is possible to cause turbine B_p to work between point t_p and u_p (Figure 4) when three generators are in operation, between points s and p when two generators are in operation, and between points n and m, when a single generator is in operation.

The variation of length of rod 18 corresponding to the three different ways of operating is chosen in such manner that for the same position of hand lever 19, corresponding to full opening of throttle valve 10, the adjusting rod of the various injection pumps is just being released by the cam determining minimum injection, for pressures which are the lower as the number of generators in operation is smaller.

Supposing that, a certain number of generators being already in action, it is desired to bring a new generator, for instance A₁, into action, it will be noted that as long as the delivery pressure of this new machine is lower than the pressure in conduit C, the action of springs 20, 20', combined with the action of the corresponding piston 13₁, produces the feed of fuel which corresponds to the operation of the apparatus independently of the turbine, for instance by injecting the maximum amount of fuel that is admissible in view of the pressure conditions.

As soon as apparatus A₁ feeds gases through conduit C, due to the opening of check valve 30₁, the regulator of the new generator is sub-

jected to the same actions as the regulators of the generators which were already in action and all the apparatus that are working, including the new one, are regulated in the same manner, their regulating means being subjected to the same actions.

In a general manner, while I have disclosed what I deem to be efficient and practical embodiments of the present invention, it must be well understood that I do not wish to be limited thereto as there might be changes made in the form, dimensions and dispositions of the parts without departing from the principle of the invention as comprehended within the scope of the appended claims.

What I claim is:

1. In the combination of a free piston generator, a turbine, a conduit connecting the exhaust of said generator with the intake of said turbine, a throttle in said conduit, and fuel feed means for said generator, the improvement comprising means for limiting the rate of fuel feed by said feed means, means responsive to the exhaust gas pressure of said generator for varying said limiting means, a single control means, means connecting said control means with said responsive means and means connecting said control means with said throttle, at least one of said connecting means including a resiliently supported pivot and lever articulated to said pivot, whereby only one of said connecting means is operative at a time.

2. In the combination of claim 1, at least one of said cam means including a cam having a partially circular outline.

3. In the combination of claim 1, said means connecting said control means with said throttle comprising means for keeping said throttle closed when said control means is moved to positions for fuel feed less than the delivery requirements of said turbine.

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