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REGULATING SYSTEM FOR POWER PLANTS, INCLUDING A FREE PISTON AUTO-GENERATOR AND A RECEIVER MACHINE SUCH AS A TURBINE

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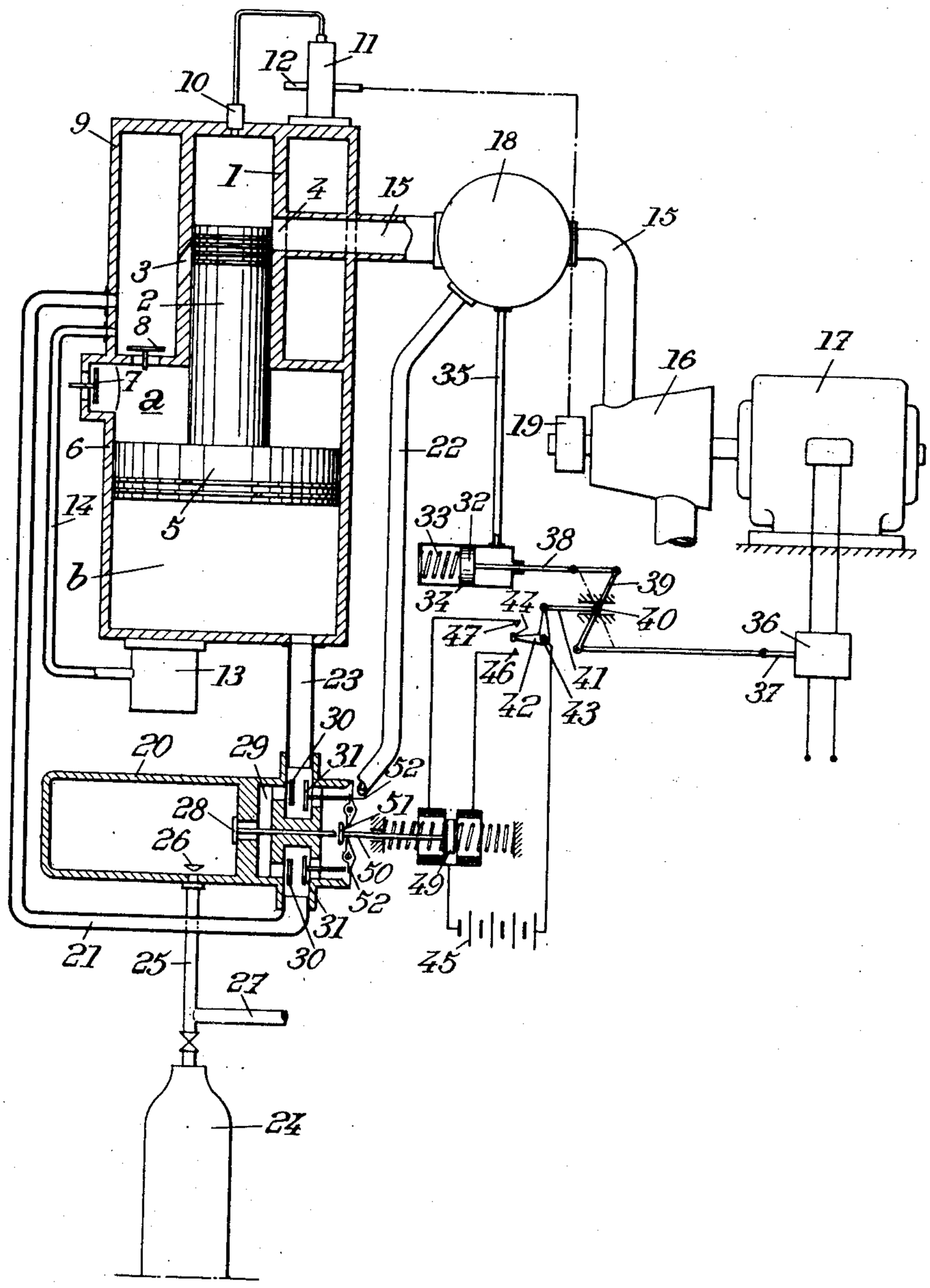

INVENTOR
ROBERT HUBER

BY
Bailey, Stephens & Huettig
ATTORNEYS

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REGULATING SYSTEM FOR POWER PLANTS, INCLUDING A FREE PISTON AUTO-GENERATOR AND A RECEIVER MACHINE SUCH AS A TURBINE

Robert Huber, Bellevue, France, assignor to Societe d'Etudes et de Participations, Eau, Gaz, Electricite, Energie, S. A., Geneva, Switzerland, a society of Switzerland

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6 Claims. (Cl. 60—13)

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The present invention relates to the regulation of power plants including a free piston auto-generator and a receiver machine, for instance a turbine, operated by the gases under pressure supplied by said generator.

The expression "auto-generator of gases under pressure" indicates a machine including an internal combustion motor portion working preferably on the two-stroke diesel cycle and a compressor portion driven by said motor portion, at least most of the air delivered, at a pressure which is preferably variable, by said compressor portion being used to feed said motor portion, which is the part of the machine which delivers the power gases intended to operate a turbine or other receiver machine.

In these auto-generators, there is interposed, between the delivery valves of the compressor portion and the inlet ports of the motor portion, an intermediate reservoir for air under pressure, which reservoir is generally constituted by the casing which surrounds the cylinder of the motor portion of the auto-generator. This reservoir will be hereinafter called "casing," although this so-called casing does not necessarily surround the power cylinder of the motor portion.

Another intermediate reservoir is generally interposed between the discharge orifices of the motor portion and the intake of the receiver machine through which said machine is supplied with power gases from the motor portion of the auto-generator. This second reservoir, which accumulates a certain amount of hot gases under pressure, will be hereinafter called "intermediate reservoir." In some cases, this intermediate reservoir may be constituted by the whole of the conduits which connect the discharge of the motor portion of the auto-generator with the intake of the receiver machine, without it being necessary to insert a reservoir proper in said system of conduits.

The receiver machine is, in most cases, constituted by a gas turbine driving, in the plants with which the present invention is preferably concerned, an electric generator, a dynamo or an alternator.

Normally, the operation of such a plant is performed by varying the amount of fuel injected into the motor portion of the auto-generator, in accordance with the load of the receiver machine. When this machine is a turbine, the injection of fuel into the motor portion of the auto-generator is controlled by a speed governor of this turbine.

Furthermore, as the auto-generators with

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which my invention is concerned include pneumatic means for accumulating power during the outward strokes of the piston or pistons and restoring it during the intervals between said power strokes so as to return said piston or pistons inwardly, regulating means are provided for varying the mass of air in said accumulator means in accordance with variations in the working pressure of the auto-generator.

These regulating means work in a satisfactory manner as long as the variations of the power to be delivered by the plant are relatively slow or little important. On the contrary, when the power required from the plant undergoes sudden and important variations, i. e. instantaneous increases or decreases, for instance equal to or higher than 10 per cent of the total power, these regulating means do not achieve sufficiently quick a response to these requirements.

The object of the present invention is to enable the power plant to adapt itself practically without delay to sudden and important variations of the power to be supplied by the plant.

Now, according to an essential feature of my invention, the power plant includes, in addition to the regulating means above referred to, an auxiliary regulating device adapted to work only in response to sudden and important variations of the load of the receiver machine for varying both the gaseous mass present in at least one of the spaces existing between the compressor portion of the auto-generator and the receiver machine and the mass of air present in the accumulator means.

A preferred embodiment of my invention will be hereinafter described with reference to the accompanying drawing, given merely by way of example and in which the only figure diagrammatically shows a power plant according to my invention including a free piston auto-generator and a gas turbine operated by the gases supplied by said generator, this turbine driving an alternator.

The free piston auto-generator includes, in conventional fashion, the following elements:

On the one hand, a motor portion operating preferably on the two-stroke diesel cycle and constiuted by a motor or power cylinder 1 and at least one power piston 2 which, during its reciprocating motion in cylinder 1, controls the inlet ports 3 and outlet ports 4 thereof;

On the other hand, a compressor portion including at least one compressor piston 5 and one compressor cylinder 6 in which said compressor piston 5 reciprocates.

Power piston 2 and compressor piston 5 are rigid with each other and constitute a free piston unit.

Compressor cylinder 6 is divided, by compressor piston 5, into two chambers one of which *a*, for instance that located on the inner side of piston 5, acts as compressor chamber proper, and is provided, for this purpose, with an inlet valve 7 and a discharge valve 8, whereas the other (chamber *b*), located on the outer side of piston 5, acts as return energy accumulator, so as to store up a portion of the energy produced in the power cylinder during the outward stroke of the movable unit and to achieve, by giving back the energy thus accumulated to the movable unit, the inward movement thereof. In the course of this inward stroke, the compressor portion compresses air and discharges it into the casing 9 of the auto-generator and, in the motor portion, the combustion air admitted into the power cylinder is compressed after power piston 2 has closed ports 3 and 4.

At the end of the inward stroke, fuel is injected into the air highly compressed in the power cylinder, this injection being performed by means of an injector 10 fed from a fuel pump 11 which is driven by the movable unit through mechanical means not shown in the drawing.

Adjustment of the amount of fuel injected per cycle is achieved by means of a control rod 12 which, for instance, rotates more or less the piston of injection pump 11 about its axis.

In order to adjust the mass of air present in pneumatic accumulator *b* to variations of the flow rate and pressure of the gases supplied by the auto-generator, this generator is fitted, in the known manner, with a so-called "stabilizer" 13 which, when it is necessary to increase the mass of air in the accumulator, causes air to enter thereinto from casing 9, whereas this stabilizer, when it is necessary to reduce the amount of air present in the accumulator, causes air to escape therefrom into casing 9.

This stabilizer may be of the construction described in my U. S. patent application Ser. No. 119,512, filed October 4, 1949, for "Improvements in Free Piston, in Particular in Free Piston Auto-generators."

During the outward stroke of the moving unit under the effect of the combustion of fuel injected into power cylinder 1, compressor piston 5 sucks in fresh air through intake valves 7 and compresses the air imprisoned in the chamber *b* of the pneumatic accumulator. When power piston 2 clears the ports 3 and 4 of the power cylinder, the combustion gases which, at this time, are still but partly expanded, escape, together with the scavenging air from the inside of casing 9, through ports 4 to be fed through conduit 15 to the intake of a gas turbine 16 which drives an electrical generator, for instance an alternator 17. In order to make the supply of gases to turbine 16 practically continuous, despite the discontinuous output of the auto-generator, an intermediate reservoir 18 is inserted in conduit 15, if the volume of said conduit is not sufficient by itself.

The injection pump regulating rod 12 is advantageously operated in response to variations in the speed of turbine 16, for instance by means of a governor 19 driven by this turbine.

The regulating effect achieved by governor 19 and stabilizer 13 is however insufficient when the plant undergoes sudden and important variations, that is to say instantaneous drops or rises of load, for instance equal to or higher than 10 per cent of the total power.

If, for instance, the power required from alternator 17 increases suddenly, an auto-generator provided only with regulating means such as above described could not instantaneously supply turbine 16 with a sufficiently increased mass of gas under pressure to enable said turbine instantaneously to supply the supplementary power that is necessary, without substantially reducing the number of revolutions thereof per unit of time. As a matter of fact, some time will be necessary to fill up all the spaces between compressor cylinder *a* and the intake of turbine 16 with gas at a pressure increased in accordance with the required increase of power. Furthermore, the mass of air contained in the accumulator would not be adapted sufficiently quick to the new conditions of operation.

In order to obviate this drawback and to make the plant capable of adjusting itself practically without delay to a sudden and important increase or decrease of the power required therefrom, this plant is further provided with an auxiliary adjustment device which, in case of a sudden increase of power, introduces, from a reservoir of gas under pressure (preferably air), a certain amount of this gas into accumulator *b*, into casing 9 and/or into intermediate reservoir 18 and, in case of sudden and important decrease of power, causes some of the gases present in the accumulator, in casing 9 and/or in reservoir 18, to escape directly into the atmosphere or into a space at lower pressure. For instance, there is provided a reservoir 20 containing a gas (such as air) under pressure (say 70 atmospheres) and which may be placed in communication, through control means to be hereinafter described, with casing 9 through a conduit 21, with intermediate reservoir 18 through a conduit 22, and with pneumatic accumulator *b* through a conduit 23.

This reservoir 20 may be filled from the usual starting air reservoir 24, through a conduit 25 and a check valve 26. In the construction shown by the drawing, a pipe 27 branching off from conduit 25 connects said reservoir 24 with the starting space (not shown) of the auto-generator. It should be noted that, in some cases, tank 20 may be constituted by the starting space of the auto-generator.

Of course, reservoir 20 communicates with casing 9, intermediate reservoir 18 and accumulator *b* only when there is an important and sudden increase of the power required from the plant. Conversely, when the power required from the plant decreases suddenly to an important degree, these spaces 9, 18 and *b* are placed in communication with the atmosphere, preferably through the same control means, so that a portion of the gas or air under pressure present in these spaces can escape quickly to the atmosphere.

It should also be noted that the sections of conduits 21, 22 and 23 are such that the pressures in the three spaces always maintain their normal values relatively to one another for different values of the load, and this both when the three spaces 9, 18 and *b* are placed in communication with reservoir 20 and when they are connected with the atmosphere. It should be noted here that the pressures in casing 9 and in reservoir 18 may have substantially the same values, respectively.

Concerning the control means, they include a valve 28 which, when opened, enables air to flow

from reservoir 20 into a distribution chamber 29. This distribution chamber 29 communicates with each of the conduits 21, 22 and 23 through one of a set of three valves 30 respectively (on the drawing, only two of these three valves 30 are visible).

Furthermore, the control means include, for each of the conduits, a discharge valve 31 (on the drawing, only two of the three discharge valves are shown) which, when opened, place the inside of these conduits in communication with the atmosphere.

These control means are operated by means of an auxiliary regulating device the working of which is based upon the fact that, under normal operating conditions, the gas pressure in the casing and in the exhaust pipe varies together with the power, in accordance with a predetermined law which is, as a rule, essentially linear. This auxiliary regulating device is therefore a differential device which operates on the one hand in response to variations of the discharge pressure of the auto-generator or of an analogous pressure (for instance pressure in casing 9 or pressure at the intake of turbine 16) and, on the other hand, in response to variations of the power required from the plant or of a factor varying in accordance with this power.

According to the embodiment shown by the drawing, use is made, for operating the auxiliary regulating device, on the one hand of the pressure existing in the intermediate reservoir 18 and, on the other hand, of the electric power supplied by alternator 17. For this purpose, the pressure in reservoir 18 acts upon one of the faces of a piston 32 the other face of which is subjected to the action of a return spring 33. Piston 32 is movable in a cylinder 34 which communicates, through a conduit 35, with the inside of reservoir 18. A wattmetric relay 36, or other element capable of indicating the power supplied by alternator 17, acts upon a rod 37. This rod 37 and the rod 38 of piston 32 are connected through suitable links with the respective ends of a lever 39 pivoted about a spindle 40 itself movable in a direction parallel to that in which rods 37 and 38 are movable.

Spindle 40 is connected, through a link 41, with one of the ends of a bell crank lever 42 pivoted about a fixed axis 43 and the other end of which carries a contact 44. Contact 44, which is connected with one of the terminals of a battery 45, is located between two fixed contacts 46 and 47 connected with an electro-valve 49 for controlling the longitudinal displacements of a rod 50 in one direction or the other, this electro-valve acting when the contact 44 carried by lever 42 closes the electric circuit of either of fixed contacts 46 and 47. As shown by the drawing, in the neutral position of lever 42, contact 44 is at a distance from both of the fixed contacts 46 and 47. Closing of the circuit of either of these fixed contacts can therefore take place only after lever 42 has pivoted through a substantial angle about axis 40.

The rod 50 of the electro-valve, when it is moved toward the left, applies its head 51 against the end of the rod of valve 28 (belonging to the control means above referred to) and thus opens this valve. Conversely, when rod 50 is moved toward the right, the head 51 thereof actuates levers 52 which open valves 31 (also belonging to the control means).

Of course, electro-valve 49 and its electric control means may be replaced by any other equivalent device, for instance by a hydraulic one.

The above described differential device, which constitutes the auxiliary regulating device, works as follows:

As long as there are no sudden and important variations of the power required from alternator 17, this variation is practically proportional to the pressure variations in reservoir 18. Consequently, lever 39 pivots, when such variations occur, about its axis 40 which remains stationary or has at most very small displacements which are not sufficient for applying contact 44 against either of contacts 46 and 47. On the contrary, when a suden variation of the power required from alternator 17 is not immediately followed by a corresponding variation of the pressure in reservoir 18, the difference between the displacements of rod 37 on the one hand and rod 38 on the other hand becomes so great that spindle 40 is moved sufficiently far to bring contact 44 against one or the other of fixed contacts 46 and 47. Contact 44 comes against contact 47 and therefore causes valve 28 to open in the case of a sudden increase of the power required from alternator 17, whereas contact 44 comes against contact 46 and therefore causes valves 31 to open when there is a sudden decrease of this power.

In the first case, air from reservoir 20 is immediately introduced into casing 9, reservoir 18 and pneumatic accumulator *b*, which immediately supplies turbine 16 with an increased amount of power gases sufficient for enabling the alternator to supply nearly immediately the increase of power required therefrom.

In the second case, air or gas present in the three spaces above mentioned is made to escape into the atmosphere, which causes a nearly immediate reduction of the amount of gases entering turbine 16, whereby any danger of racing thereof is excluded.

Contact 44 leaves contact 46 or 47 shortly before the pressure in reservoir 18 has reached the value corresponding to the new pressure required, whereby the valve system is returned to its neutral position for which the respective valves are closed.

Due to the intervals provided between contact 44 in its neutral position and each of contacts 46, 47, a slight unbalance between the pressure existing in reservoir 18 and the power measured by wattmetric relay 36 may occur without operating the regulating device. This device is left inoperative as long as the power variations, even if they are sudden, are relatively small, for instance lower than 10% of the total power. In order to bring the regulating device into operation, the power variation must be both sudden and higher than 10% of the total power.

It should also be noted that the amounts of air which, in case of sudden and important variations of the power, are to be supplied by reservoir 20 or withdrawn from spaces 9, 18 and *b* are relatively small since, anyway, within a period of some seconds, the conditions of operation of the auto-generator are to be adapted to the new power requirements. Consequently, it suffices to give relatively small dimensions to tank 20.

In the device above described, the factor variable in response to variations of the required power is the electric power supplied by alternator 17, but this factor might also be the variable displacement of speed governor 19 or the position of the ends of the outward strokes of movable unit 2—5. In this last case, discharge of air from

chambers 9, 18 and *b* may for instance be produced when the movable unit reciprocating movement has its minimum amplitude, and, on the contrary, these spaces may be filled with air under pressure when this reciprocating movement has its maximum amplitude.

Of course, addition of air or exhaust of gas may take place in only one of the spaces above mentioned.

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

What I claim is:

1. In combination, a free piston auto-generator including a power cylinder and a compressor cylinder fixed with respect to each other, a power piston and a compressor piston freely movable in said cylinders respectively, said two pistons being rigid with each other to form together a moving unit, means for feeding air under pressure from said compressor cylinder to said power cylinder, a discharge conduit leading from said power cylinder, a pneumatic energy accumulator for storing up energy from said moving unit during the power strokes thereof and restoring said energy to said unit during the return strokes thereof and means for feeding fuel to said power cylinder, a receiver machine having its intake connected to said discharge conduit so as to be operated by the gas stream issuing from said power cylinder, means for regulating said fuel feed means in response to variations in the load of said machine, means for varying the mass of air present in said accumulator in response to variations in the working pressure of said auto-generator, and an auxiliary regulating device including a reservoir of gas under pressure and control means responsive to sudden increases in the load of said machine exceeding a given value for placing said reservoir in communication with at least one of the spaces included in said power cylinder air feeding means and said discharge conduit and with said accumulator and responsive to sudden decreases in the load of said machine exceeding a given value for placing at least one of the above mentioned spaces and said accumulator in communication with the atmosphere.

2. In combination, a free piston auto-generator including a frame, a power cylinder and a compressor cylinder both fixed with respect to said frame, a power piston and a compressor piston freely movable in said cylinders respectively, said two pistons being rigid with each other to form together a moving unit, means including a supercharging reservoir for feeding air under pressure from said compressor cylinder to said power cylinder, a discharge conduit leading from said power cylinder, a pneumatic energy accumulator for storing up energy from said moving unit during the power strokes thereof and restoring said energy to said unit during the return strokes thereof and means for feeding fuel to said power cylinder, an intermediate reservoir in communication with said discharge conduit, a receiver machine having its intake connected to said intermediate reservoir so as to be operated by the gas supplied by said power cylinder, means for regulating said fuel feed means in response to variations in the load of said machine, means for varying the mass of air present in said accumulator in response to variations in the working pressure of said auto-generator, and an auxiliary regulating device including a reservoir of gas under pressure and control means responsive to sudden increases in the load of said machine exceeding a given value for placing said last mentioned reservoir in communication with at least one of the two first mentioned reservoirs and with said accumulator and responsive to sudden decreases in the load of said machine exceeding a given value for placing at least one of the two first mentioned reservoirs and said accumulator in communication with the atmosphere.

3. A combination according to claim 2 in which said control means include two conduits interposed between said third mentioned reservoir on the one hand and said two first mentioned reservoirs on the other hand, respectively, the cross sections of said conduits being calculated to keep the respective pressures in said two first mentioned reservoirs substantially equal to each other.

4. A combination according to claim 1 in which said auto-generator includes a starting air reservoir, and the gas reservoir of claim 2 is connected with said starting air reservoir for feed therefrom.

5. In combination, a free piston auto-generator including a power cylinder and a compressor cylinder fixed with respect to each other, a power piston and a compressor piston freely movable in said cylinders respectively, said two pistons being rigid with each other to form together a moving unit, means for feeding air under pressure from said compressor cylinder to said power cylinder, a discharge conduit leading from said power cylinder, a pneumatic energy accumulator for storing up energy from said moving unit during the power strokes thereof and restoring said energy to said unit during the return strokes thereof and means for feeding fuel to said power cylinder, a receiver machine having its intake connected to said discharge conduit so as to be operated by the gas stream issuing from said power cylinder, means for regulating said fuel feed means in response to variations in the load of said machine, means for varying the mass of air present in said accumulator in response to variations in the delivery pressure of said auto-generator, and an auxiliary regulating device responsive exclusively to sudden variations in the load of said machine exceeding a given value for varying both the gaseous mass in at least one of the spaces included in said power cylinder air feeding means and said discharge conduit and the mass of air in said accumulator to adapt the working of said auto-generator to said sudden variations, said auxiliary regulating device being operative differentially in response to variations of the pressure in said discharge conduit and to variations of the load of said machine.

6. In combination, a free piston auto-generator including a frame, a power cylinder and a compressor cylinder both fixed with respect to said frame, a power piston and a compressor piston freely movable in said cylinders respectively, said two pistons being rigid with each other to form together a moving unit, means including a supercharging reservoir for feeding air under pressure from said compressor cylinder to said power cylinder, a discharge conduit leading from said power cylinder, a pneumatic energy accumulator for storing up energy from said moving unit during the power strokes thereof and restoring said energy to said unit during the return strokes

thereof and means for feeding fuel to said power cylinder, an intermediate reservoir in communication with said discharge conduit, a receiver machine having its intake connected to said intermediate reservoir so as to be operated by the gas supplied by said power cylinder, means for regulating said fuel feed means in response to variations in the load of said machine, means for varying the mass of air present in said accumulator in response to variations in the working pressure of said auto-generator, a reservoir of gas under pressure, a set of valves for controlling the communication of said third mentioned reservoir with the two first mentioned reservoirs and with said accumulator, respectively, a set of valves for controlling the communication of said two first mentioned reservoirs and said accumulator respectively with the atmosphere, a device for opening either of said two sets of valves, a part slidable in said frame to operate said device when moved beyond a given distance in one direction or the opposed one, a lever pivoted at an intermediate point thereof to said part, means operative in response to variations of the pressure in said intermediate reservoir for moving one end of said lever in said direction or the opposed one according as the pressure in said intermediate reservoir increases or decreases, respectively, and means operative in response to variations of the load of said machine for moving the other end of said lever in said direction or the opposed one according as said load decreases or increases respectively.

ROBERT HUBER.

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