(No Model.) 5 Sheets—Sheet 1.

J. F. PLACE.

GAS ENGINE.

No. 348,998. Patented Sept. 14, 1886.

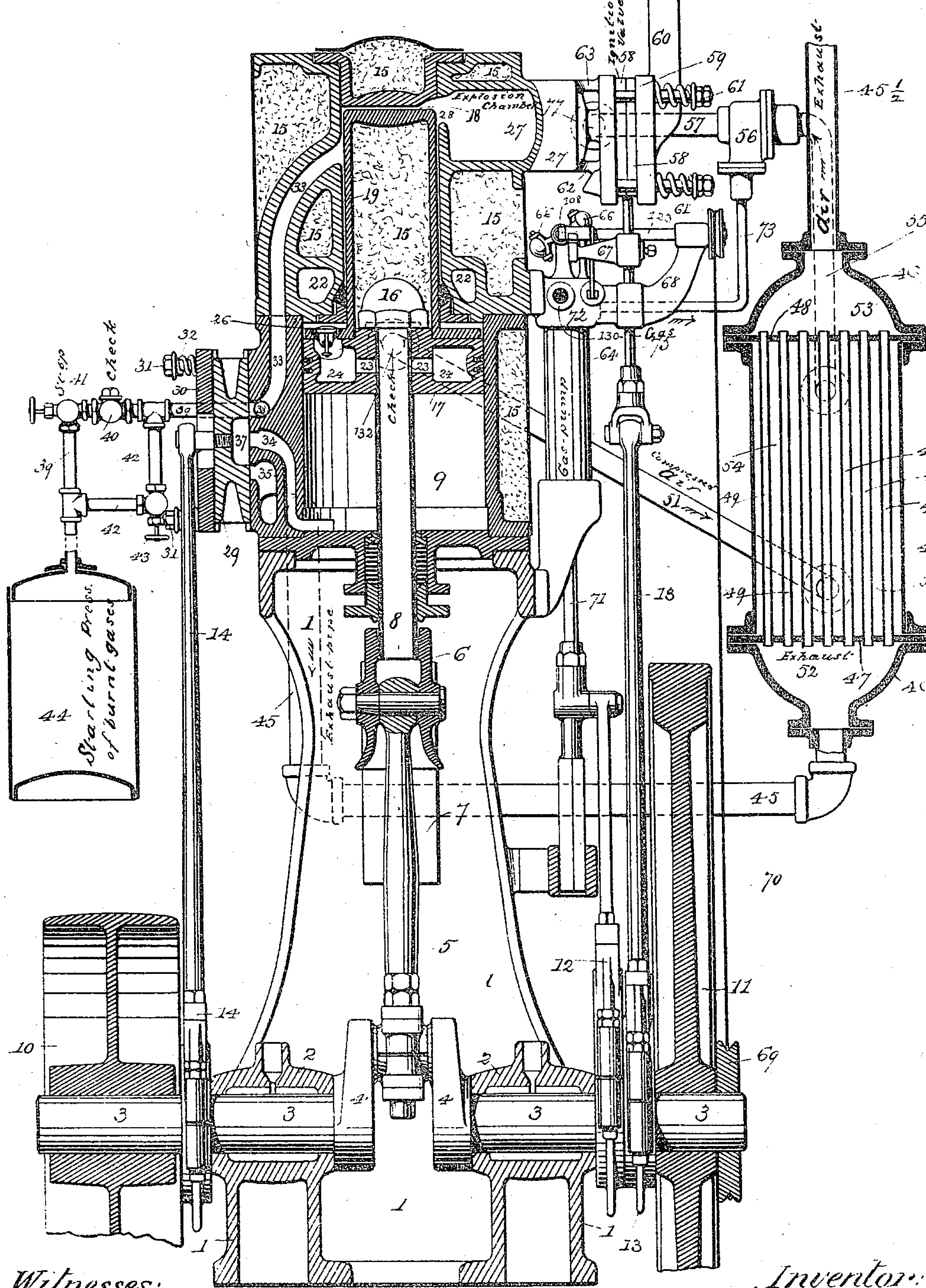

Fig. 1

Witnesses:

Inventor:

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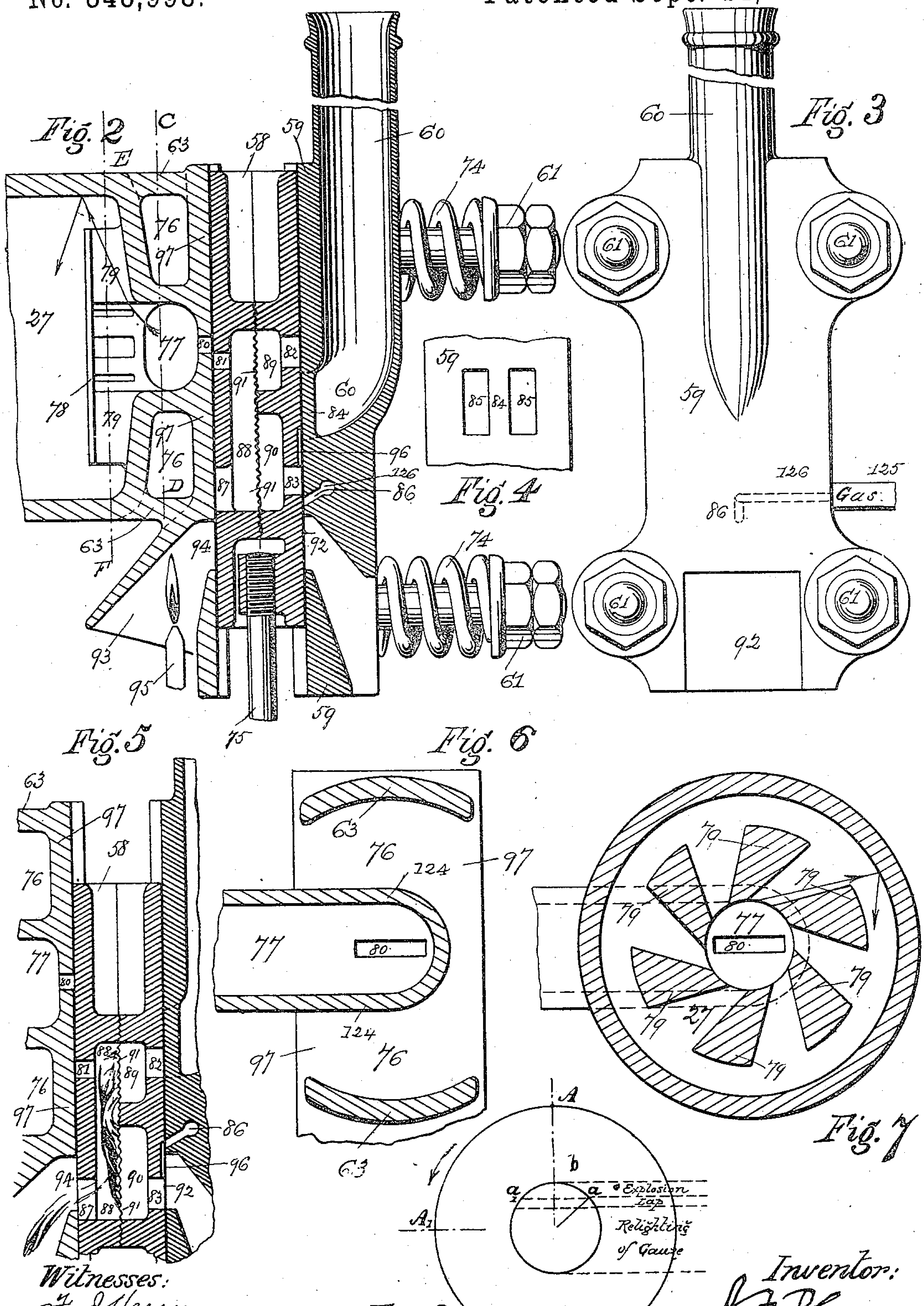

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GAS ENGINE.

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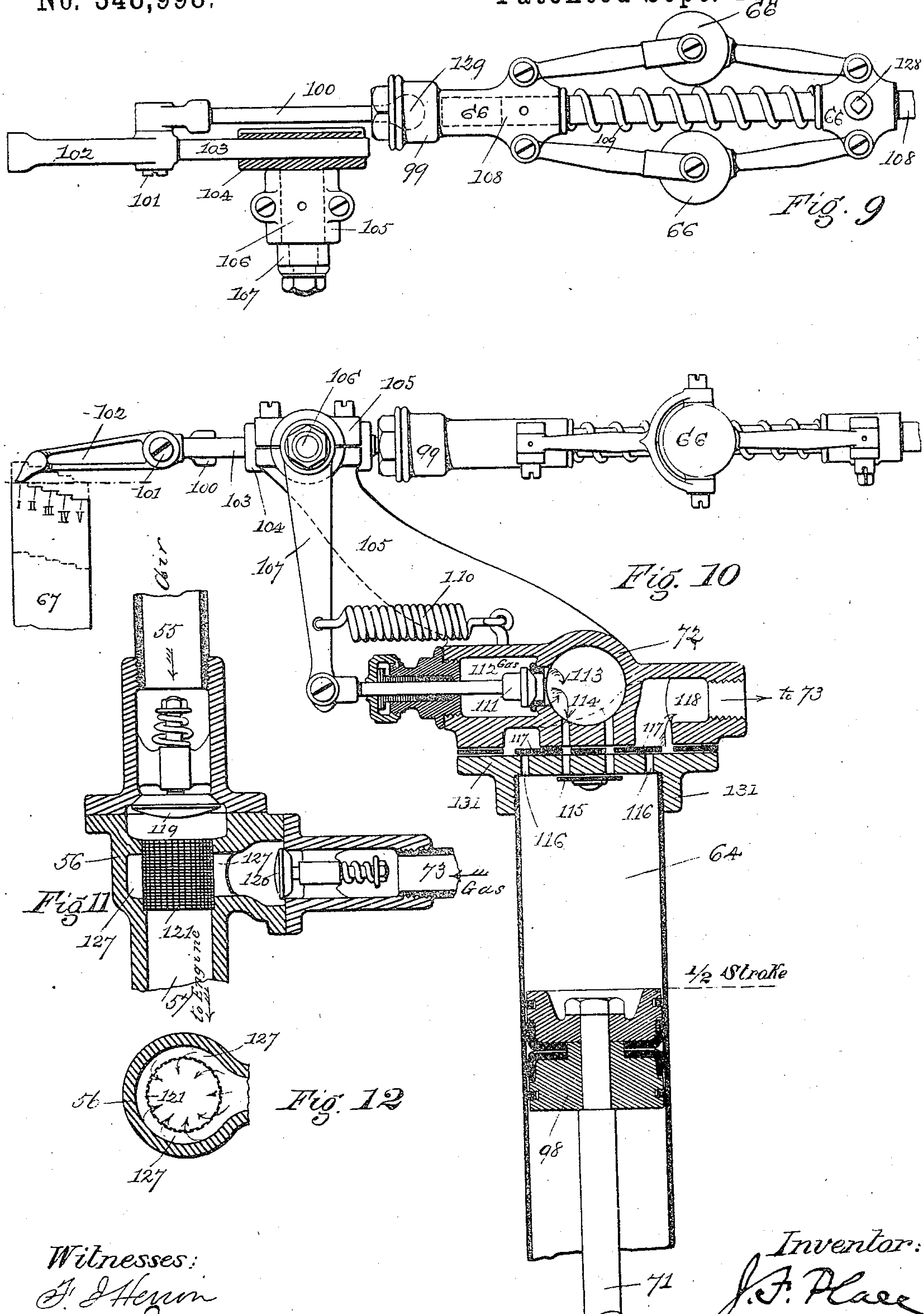

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(No Model.) 5 Sheets—Sheet 4.

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GAS ENGINE.

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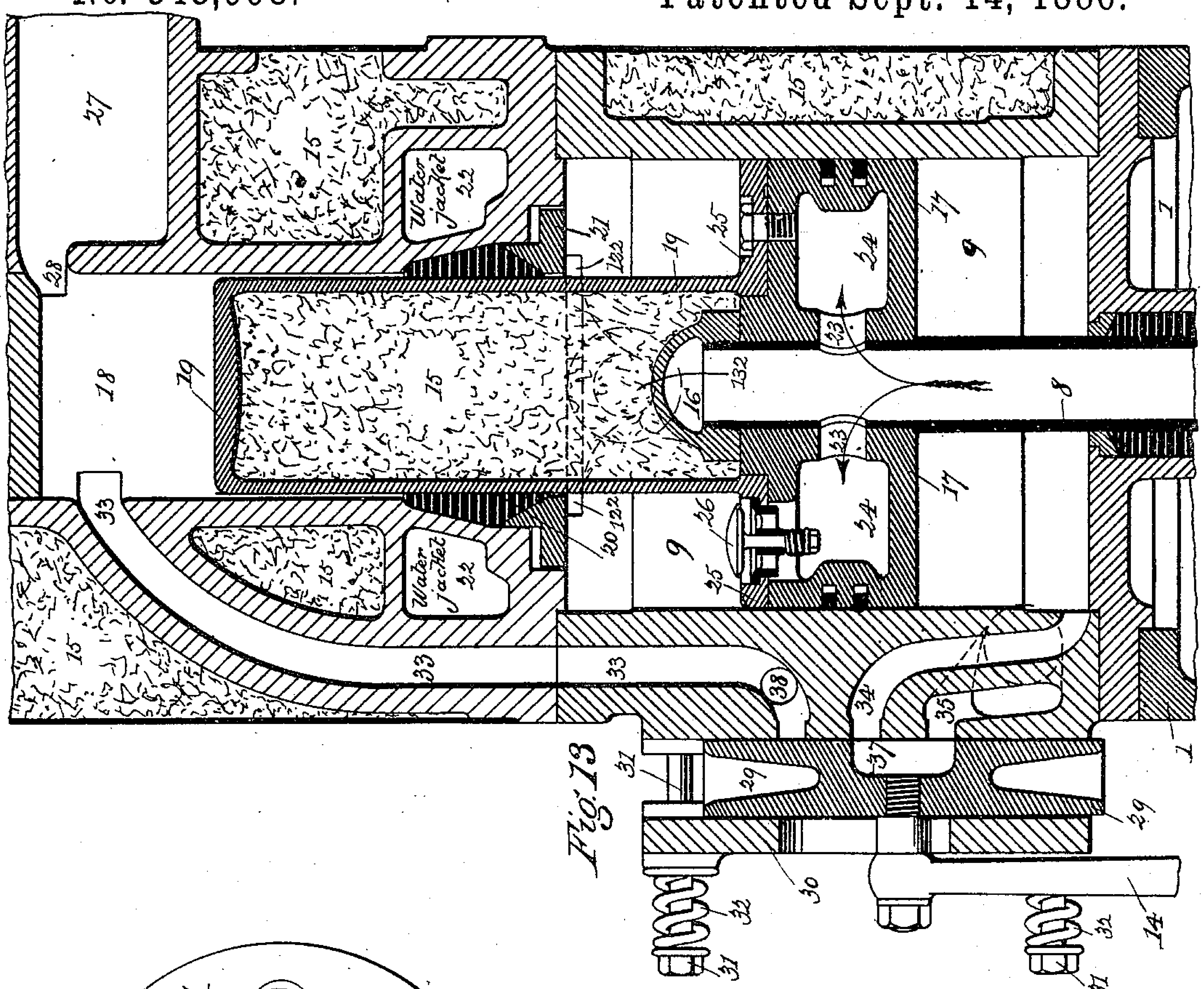

Fig. 13

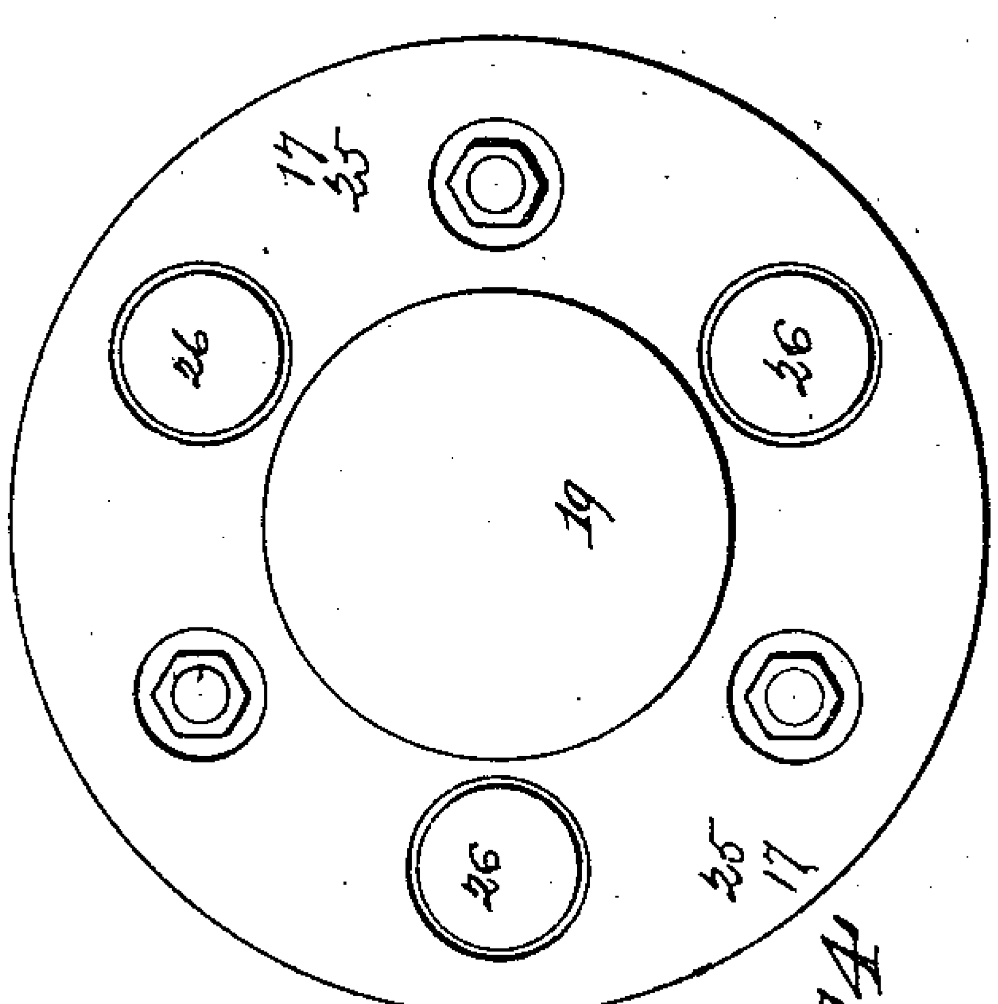

Fig. 14

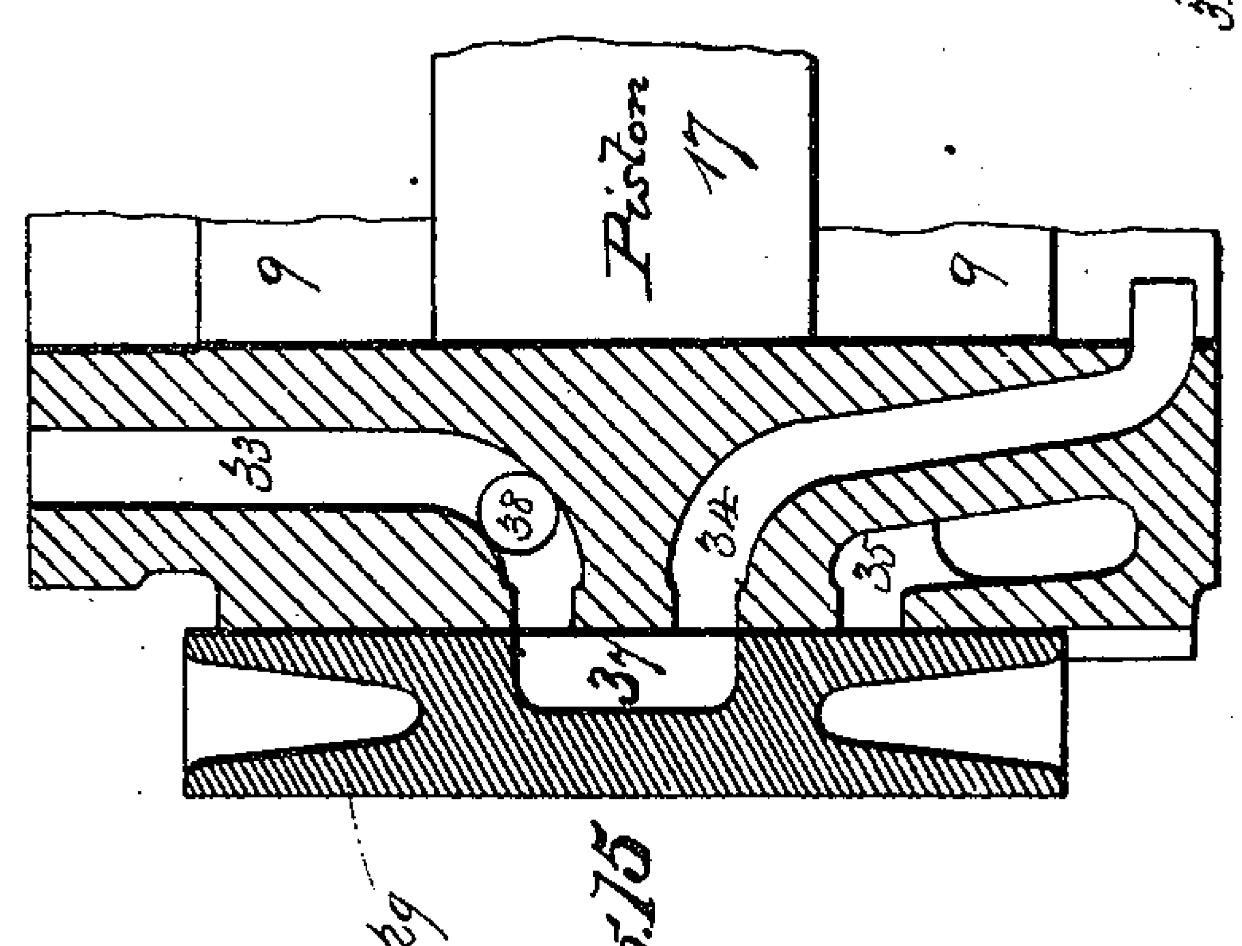

Fig. 15

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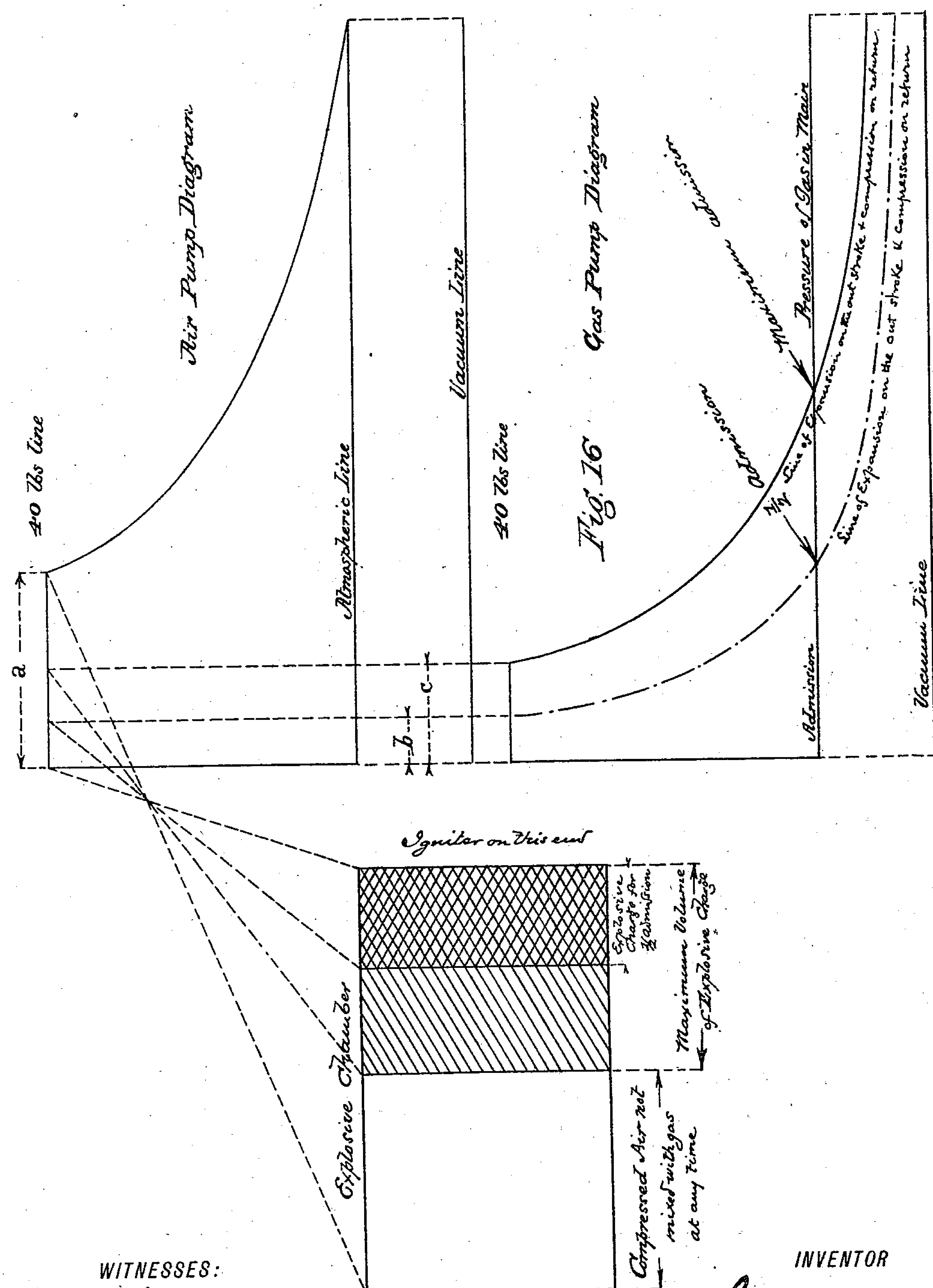

WITNESSES:

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J. F. Place

UNITED STATES PATENT OFFICE.

JAMES FRANK PLACE, OF NEW YORK, N. Y.

GAS-ENGINE.

SPECIFICATION forming part of Letters Patent No. 348,998, dated September 14, 1886.

Application filed February 3, 1886. Serial No. 190,692. (No model.)

To all whom it may concern:

Be it known that I, JAMES FRANK PLACE, a citizen of the United States, and a resident of the city, county, and State of New York, have invented certain new and useful Improvements in Gas-Engines, of which the following is a description, reference being had to the accompanying drawings, forming part of this specification.

My invention relates to that class of gas-engines in which the explosive charge is compressed before ignition and expanded successively in two cylinders after ignition—viz., compound compression gas-engines; and my invention consists in various improved devices and combinations of devices having for their object, respectively, a high range of expansion of the burned gases, the conversion into work of a larger proportion of the heat in said gases than has heretofore been attainable, the thorough mixing of the air and gas before ignition, the reliable ignition of the explosive charge, and the regulation of the engine by varying automatically the volume of the explosive charge without varying its degree of inflammability.

In the accompanying drawings similar numbers of reference designate corresponding parts in the several figures.

Figure 1 is a vertical section through the center line of my engine, some of the parts, however, which are too small to illustrate properly in section on this scale, and which are shown on a larger scale in the other figures, being represented in elevation. Fig. 2 is a vertical section of the igniting-valve and its seat and backing-plate through the same vertical plane as that of Fig. 1, and represents this valve in the position which it occupies just before an ignition takes place. Fig. 3 is a rear elevation of the backing-plate for the igniting-valve. Fig. 4 is a view of the vent or chimney ports in the backing-plate of the igniting-valve. Fig. 5 is a vertical section of the igniting-valve through the same plane as Fig. 2, and shows the valve in the position which it occupies when at the lowest point of its course between two ignitions. Fig. 6 is a vertical cross-section on line C D of Fig. 2. Fig. 7 is a vertical cross-section on line E F of Fig. 2. Fig. 8 is a diagram showing the relative positions and movements of the igniting-valve eccentric and of the main crank-pin. Fig. 9 is a plan of the governor which controls the supply of gas to the gas measuring and compressing pump. Fig. 10 shows this pump in vertical section, illustrating the construction of its admission and emission valves, and also shows in elevation the governor represented in plan in Fig. 9. Fig. 11 represents a horizontal section of the combined gas and air valves through which the gas and air under compression are admitted to the igniting-chamber. Fig. 12 is a vertical cross-section at line G H of Fig. 11. Fig. 13 is a vertical cross-section of the two cylinders, showing the pistons at half-stroke and illustrating the position occupied by the slide-valve which operates the cylinders when the pistons are at half-downstroke. Fig. 14 is a plan of the pistons. Fig. 15 is a vertical cross-section of a portion of the large cylinder, showing the position occupied by the slide-valve when the pistons are at half-upstroke. Fig. 16 represents two theoretical diagrams, respectively, of the gas-pump and of the air-compressing cylinder, and serves to furnish a graphic illustration of my method of varying the volume of the explosive charge without at any time varying its degree of inflammability.

Referring to Fig. 1, it is seen that my engine is shown of the vertical inverted type, with the cylinders steepled or tandem—that is, set one above and in line with the other—the two pistons being attached to the one piston-rod and connecting-rod, and operating one crank-pin. I do not wish to restrict myself in this application to the vertical type of engine, as my engine can be built and operated horizontal, and all parts of the following description would apply to this latter type, with the exception that the terms "pistons moving up or down," "upstroke," and "downstroke," should read, for a horizontal engine, "pistons moving in or out," "instroke," and "outstroke," &c. 1 is the frame or housing of the engine. 2 are the main bearings of the crank-shaft 3. 4 are the cranks. 5 is the connecting-rod, attached to the cross-head 6, working on the slides 7. 8 is the piston-rod, which is hollow, closed at its upper end by the cap-nut 16, and open at its lower end in the cross-head 6. 9 is the large or low-pressure cylinder, which is double-acting, and in which is fitted the piston 17. This cylinder is surmounted by the small or high-pressure cylinder 18. This latter is single-acting, and in it is fitted the plunger 19, attached to and concentric with the piston 17. The plunger 19 is only fitted loosely to its cylinder 18, and the joint around it and between the two cylinders is formed by the packing 20 at the mouth of the cylinder 18, which packing is secured by the gland 21, and is kept cooled off by a water-jacket, 22, formed in the walls of the cylinder 18, and through which a circulation of water is maintained while the engine is in operation. This water-jacket 22, however, is shaped so as to merely surround the packing 20 without extending far enough to chill the working-surfaces of the cylinder. Both the cylinders 9 and 18 are surrounded with jackets or clothing 15, of non-conducting material—such, for instance, as mineral wool—and the plunger 19, which is cast hollow, is filled with similar material. The piston 17 (see, also, Figs. 13, 14, and 15) is cast hollow, the cored part being represented by 24. Two or more apertures, 23, in the hub to which the hollow piston-rod 8 is attached and through the sides of said piston-rod, establish a communication from the core 24 of the piston 17 through the apertures 32, the hollow rod 8, and the cross-head 6 to the atmosphere. The flange 25, formed on the base of the plunger 19, serves as a follower for the piston 17, to which it is bolted, as may be readily understood from Figs. 13 and 14, and in this flange or follower 25 are set three or more puppet-valves, 26, opening from the core 24 into the upper end of the cylinder 9. At the upper end and to one side of the cylinder 18 is cast or attached a chamber, 27, which I call the "igniting" or "explosion" chamber. To this chamber is attached the igniting-valve, and it is in this chamber that the explosive charge of compressed air and gas is ignited at the beginning of each and every downward stroke of the pistons. A port, 28, connects the chamber 27 and the cylinder 18. On the side of the cylinder 9 is planed a valve-seat, on which operates the slide-valve 29, worked by the eccentric 14, set at quarters with the main-crank pin. The valve 29 is held to its seat by the backing-plate or cover 30, secured in place by the studs 31, provided with the springs 32, for holding the valve to its seat, said springs being of sufficient tension to counteract any pressure tending to force the valve 29 off its seat. The valve 29 regulates three ports, 33, 34, and 35. The port 33 leads from the valve-seat to the upper end of the cylinder 18. The port 34 leads from the valve-seat to the lower end of cylinder 9, and the third port, 35, leads from the valve-seat to the exhaust-pipe 45. The valve 29 has a recess, 37, in its face, which is of sufficient width to put in communication alternately the ports 33 with 34 and 34 with 35 without it being possible, however, for the ports 33 and 35 to be in direct communication with each other at any time. In the port 33 is a port, 38, opening to one side off the valve-seat. To this port 38 is attached a pipe, 39, leading to an outside tank or receiver, 44, with an intervening stop-valve, 41, and check-valve 40, the latter opening from the port 38 to the receiver 44. On the pipe 39 is provided a branch or by-pass pipe, 42, with a stop-valve, 43, which by-pass serves to establish a communication between the receiver 44 and the port 38, without making use of the part of the pipe 39 on which are located the stop-valve 41 and the check-valve 40. At the upper part of the upper or compressor end of the large cylinder 9 is a port, 122, through which the contents of that end of the cylinder 9 may be discharged into the pipe 51, which latter carries them to the combined air and gas admission valve 56. On the pipe 51, as close as possible to the cylinder 9, is located a check-valve opening from the cylinder out. This valve is not represented in these drawings, as it is behind the cylinder; but its position is indicated in Figs. 1 and 13 by 132, and I shall designate the valve by that number in this description. The pipe 51 is not shown attached directly to the valve 56. It is made to lead the contents of the upper end of cylinder 9 on their way to said valve first to a regulator or economizer, 46. This economizer, constructed on the same general lines as an ordinary steam-engine surface-condenser, consists of three superposed or successive contiguous chambers, 52, 54, and 53, separated from each other, respectively, by the tube-sheets 47 and 48, in which are secured the open tubes 49. These tubes form a connection between the chambers 52 and 53. The pipe 51 delivers its contents at one end of the chamber 54, and from the other end of said chamber a pipe, 55, carries them to the above-mentioned valve 56. The port 35 (when the valve 29 uncovers it) allows the contents of the lower end of the cylinder 9 to be exhausted into the exhaust-pipe 45. This pipe may be led to any convenient point, but is shown in this case attached to the chamber 52 of the economizer 46. Therefore gases exhausted through the port 35 traverse the chamber 52; hence through the tubes 49 pass into the chamber 53, and from that through the pipe 45½ are led to waste. 10 is the power-pulley of the engine. 11 is the fly-wheel. 12 is an eccentric, which operates the gas measuring and compressing pump 64. 13 is an eccentric, which operates the igniting-valve 58. 69 is a pulley, which runs the governor 66 by means of the belt 70 and shaft 123, bevel-geared with the governor-shaft or spindle 108, and supported on a suitable bracket, 68.

In Figs. 2 to 7, inclusive, which are intended to illustrate the construction of the igniting-valve, 58 represents the said valve. This valve works back and forth on a seat, 97, formed on the vertical outer end of the explosion or ignition chamber 27, this seat 97 not being the outer wall proper of the chamber 27, but being cast away from it, although connected to it by the webs or ribs 63, and by the webs 124. These latter surround the port 80 on the face 97, forming around this port a pocket or channel, 77, which extends into the chamber 27, and which has also a lateral extension between the face 97 and the end wall of the chamber 27. To this lateral extension is attached the pipe 57, leading from the combined gas and air admission valve 56, so that this valve may discharge its contents into the pocket 77. From the pocket 77 the gases are admitted to the igniting-chamber 27. As the charge leaves the pocket 77 to enter the chamber 27, it meets the deflecting-plate 78, which causes the charge to be thrown out to the sides of the chamber 27 at the same time that a slight conical inclination to the end wall of the chamber gives a slightly-forward direction to the flow, the effect of both deflections on the current of entering charge resulting in the direction illustrated by the arrows in Fig. 2. The deflecting-plate 78 is secured in place by means of a set of lugs, 79, cast on the inside of the end wall of the chamber 27 around the mouth of pocket 77, the ends of which lugs 79 are faced off parallel with the face 97, to receive the deflecting-plate 78. The lugs 79 are so shaped that their sides deviate from the radii of a circle, and therefore the entering charge, in addition to the deflection which it receives from the plate 78, is given a whirling motion by passing between the lugs 79, as indicated by the arrow in Fig. 7. Below the lower web, 63, on the face 97, is a port, 94, forming the apex of a hood, 93, under which is a permanent gas-burner, 95, (preferably a Bunsen burner.) The igniting-valve 58 is made in two parts, which are securely bolted together with an intervening layer of wire-gauze, 91, and the two halves of the valve are so shaped that when put together with the gauze 91 three compartments or lobes are formed, 88, 89, and 90, the chamber 88 being on the side nearest the igniting-chamber 27, and the chambers 89 and 90 being in the opposite half of the valve. The valve 58 is faced on both sides, one side running on the seat 97, while the other side is pressed upon by the plate or cover 59, held up to its seat by the studs 61, provided with the springs 74, of sufficient tension to withstand any pressure tending to throw the valve off the seat 97. In the face of the valve, and opening into the lobe 88, are the ports 81 and 87, while in the reverse face of the valve are the ports 82 and 83, the latter connecting with the lobe 90, and the former with the lobe 89. On the back plate or cover, 59, is cast the chimney or vent-pipe 60. The ports 85 85 on the face of the cover 59 open into this chimney. Two ports are used instead of one, and an intervening bridge, 84, is provided so as to avoid ever uncovering and opening to the chimney 60 a small vertical groove or channel, 96, dug out on the reverse face of the valve 58, and extending a little distance above the port 83. A hole, 126, is drilled horizontally from one side of the plate 59 to its center, where it meets another hole, 86, drilled with an upward slant from the face of said plate 59 just above the port 92. The hole 126 is made to connect with the pipe 125, attached to the gas-supply.

In Figs. 9 to 12, inclusive, which are intended to illustrate the construction of the gas measuring and compressing pump 64, governor 66, and combined air and gas admission valve 56, 66 represents the governor, which is of the ordinary ball type, the spring 109 being intended to draw the balls to the center, and the centrifugal force causing them to fly apart. The governor is here shown at rest. The governor is set on the end of the horizontal shaft 108, which runs in suitable bearings. (Not shown in these drawings.) This shaft is bevel-geared with the shaft 123, run by the belt 70 and pulley 69, and is at right angles to the plane of section Fig. 1, in which therefore the governor only appears in end elevation. The outer end of the governor can play back and forth upon the end of the shaft 108, while the other end is secured firmly thereto by the set-screw 128. The outer end, beyond the end of the shaft 108, is in the shape of the ball-and-socket joint 99, which catches the ball 129 of the link 100. The other end of the link 100 is hinged to a piece or fitting, 102 103, composed of a round straight part, 103, the center line of which is parallel with and on the same horizontal plane as the center line of shaft 108, and of a pointed toe-shaped part, 102, extending on the other side of the pin 101, which is the hinge or pivot by means of which the link 100 is attached to the piece 102 103. In a horizontal bearing, 105, carried by or supported upon the head 72 of the pump 64, the axis of which bearing is normal to that of the shaft 108, lies a short shaft or trunnion, 106, having outside of the bearing 105 on one side a head or cross piece, 104, and on the other side a projecting end, to which is keyed or otherwise securely attached an arm, 107. The head 104 is bored at right angles to the axis of 106, to receive the round part 103 of the piece 102 103, as shown very distinctly in Fig. 9, a plan in which the head 104 on the shaft 106 has been shown in section to illustrate the connection between it and the piece 102 103. The arm 107 is set so as to stand vertical when the piece 103 is horizontal. The arm 107 is attached to the stem of the valve 111, which valve serves to close the opening between the two chambers 112 and 113, formed in the head 72 of the gas-pump 64. A suitable spring, 110, tends to draw the lever 107 toward the pump, and thereby to close the valve 111, the valve being closed when the arm 107 stands, as shown, vertical, or about so. The chamber 112 is connected to the gas-supply through the opening 130. (Shown in Fig. 1.) The chamber 113 is connected with the chamber 112, as stated above, through the opening controlled by the valve 111, and is connected to the pump-barrel by means of the ports 114, a number of which are drilled in a circle. A false head, 131, is provided, through which the ports 114 are drilled into this cylinder, and a sheet of rubber is interposed between the head 72 and the false head 131 to form a valve, 117, for the ports 116, drilled on a circle larger than that of the ports 114. Another sheet of rubber, 115, serves to close the ports 114. The construction is made obvious by the drawings, which show, without any further explanation, that the gas is admitted to the pump from the chamber 112 through the opening controlled by the valve 111, through the chamber 113, and through the ports 114, and under the valve 115, the valve 117 being drawn to its seat during this period of admission, and that during the return or compression stroke the gas is forced out of the pump by the piston through the ports 116 and beyond the valve 117 into the annular recess or chamber 118, the valve 115 having during this time been held to its seat by the pressure in the pump. The discharge recess or chamber 118 in the head 72 is connected to the pipe 73, which leads the compressed gas to the combined air and gas valve 56. This valve, or, rather, this fitting, is made, as shown, in several pieces, which, when put together, assume the shape of a T. The main or straight channel, at either side of its junction with the lateral one, is contracted, and a sleeve or tube of wire-gauze, 121, the axis of which coincides with that of the main channel, is slipped and secured between the two contractions above referred to. An annular space, 127, closed at both ends, is thereby formed between the body of the fitting 56 and the tube of wire-gauze 121. This annular space is in direct communication with the lateral branch of the T, while it has no communication with the main channel except through the wire-gauze 121. The pipe 73, attached to the lateral branch of the T, brings to the annular space 127 the gas compressed by the gas-pump 64, an intervening check-valve, 120, being provided in the fitting 56, and the pipe 55 brings the compressed fluid from the compressor end of the large cylinder 9 to one end of the main channel, provided, also, with a check-valve, 119. The other end of the main channel is fastened to the pipe 57, which leads to the port 77, Fig. 2, and hence to the igniting-chamber 27.

I will now describe the working of my engine, showing first how it operates as a whole, and taking up afterwards the different parts and describing their individual mechanism and mode of operation. I wish to state at the outset that owing to lack of room the receiver 44 and the economizer 46, Fig. 1, are shown neither in actual working proportions as regards the rest of the engine nor in the position which they would occupy in practice, being represented, in fact, without any apparent support. This, however, is immaterial, as both these appliances may be set wherever most convenient of erection. If desired, the receiver 44 could be formed by coring out portions of the frame of the engine, &c. In Fig. 1 the engine is on its upper center, in the position it occupies just before the ignition of the charge of gas and air contained in the igniting-chamber 27. The slide-valve 29 (the eccentric 14 of which is at right angles to the cranks) is in mid-position, and both the ports 33 and 35 are covered. As the explosion occurs, the burned gases force down the plunger 19 and the piston 17, to which it is attached, and the slide-valve 29, which is ahead of the pistons, also travels downward and uncovers the port 35, thereby permitting the contents of the lower end of the cylinder 9 to exhaust through port 34, cavity 37, and port 35 into the pipe 45. As the piston 17 goes down, the check-valve 132 on the pipe 51 closes and a partial vacuum is formed in the upper part of cylinder 9, which causes the valves 26 to open and atmospheric air to be admitted from the outside through the cross-head 6, (which should be designed to simulate in shape at its lower end the mouth of a funnel,) the hollow piston-rod 8, the ports 23, the core 24 of the piston 17 and the valves 26 into the upper part of said cylinder 9. At mid-stroke going down the parts assume the position shown in Fig. 13. The valves 26 are off their seats, the course of the air entering the upper port of cylinder 9 being represented by arrows, and the valve 29 has reached the limit of its downward stroke, opening the port 35 to its full extent. It should be stated that the eccentric 12, which operates the gas-pump 64, is set with the cranks, so that the strokes of said pump are synchronous with those of the pistons. At the same time, therefore, that the pistons are going down and a charge of air is being drawn into the upper end of the cylinder 9, the pump-piston is going down and drawing in a charge of gas. At the end of the stroke, when the crank-pin reaches its lower center, the valve 29 is again in the position shown in Fig. 1, with the difference that it is now on its upward stroke, with the result that, as soon as the center is passed, the port 33 begins to uncover and the port 35 is closed. This causes the burned gases, which have already been expanded and done work in the cylinder 18, to pass through the ports 33 and 34 into the lower end of cylinder 9, and on account of the difference in the areas of the two cylinders the burned gases force the pistons upward, in doing which the said gases are further expanded and do additional work. In mid-position on the upstroke the valve 29 reaches the highest point of its course, as shown in Fig. 15—viz., the port 33 is wide open, and during the last half of the upstroke the valve gradually lowers, till, as the center is reached, it again assumes the position shown in Fig. 1. As soon as the cranks turn, the lower center and the pistons begin their upward stroke, the valves 26 close, and the air with which the upper part of the cylinder 9 was filled during the downstroke, is compressed by the piston 17 and forced out through the port 122, the check-valve 132 and the pipe 51, to the combined air and gas admission valve 56. The gas-pump 64 likewise compresses during the upstroke the gas which it drew in during the downstroke, and forces it through the pipe 73 to the same valve 56. From the valve 56, both the gas and the air which mingle therein enter the chamber 27, and when the upstroke is completed, the parts all being in the position shown in Fig. 1, the igniting-valve, operated by the eccentric 13, causes the explosive charge in the chamber 27 to be fired and the cycle of operations above described to be repeated—viz., on the downstroke expansion of the burned gases in the high-pressure cylinder 18, expulsion of fully-expanded gases from lower end of low-pressure cylinder 9, admission of air to the upper end of said cylinder, and admission of gas to the gas-pump, and on the up or return stroke admission of gases from high-pressure cylinder 18 to the lower end of low-pressure cylinder 9, and their further expansion therein compression of air in the upper or compressor end of low-pressure cylinder 9, compression of gas in the gas-pump, and admission to the chamber 27 of a fresh charge of gas and air for explosion at the beginning of the next downward stroke.

The receiver or tank 44 is used to store at periods when the engine is running a sufficient amount of the gases under pressure to start up the engine again after the next stoppage by admitting said gases to the cylinders. This is done in the following manner: While the engine is running, the valve 43 being closed, the valve 41 is opened. At every explosion a certain amount of the gases is forced through port 38, pipe 39, check-valve 40, and valve 41 into the receiver 44. Neither can the gases escape into the low-pressure cylinder when the port 33 is open to the port 34 during the up or return stroke, as they are retained by the check-valve 40. When, after a few strokes, the pressure in the receiver 44 has reached the initial pressure of the explosion, which is the maximum to be obtained, the valve 41 should be shut off. After a stoppage, when it is desired to use the pressure stored in the receiver 44 to start up the engine, it is only necessary to open the valve 43, by doing which the contents of the receiver 44 are allowed to escape through the port 38 and the by-pass pipe 42 into the port 33. On the downstroke, when the valve 29 covers the port 33, the pressure acts on the high-pressure plunger 19 alone. On the upstroke, when the port 33 is open to the port 34, the pressure acts on the plunger 19 and on the lower side of piston 17, as well causing them to move upward on account of their difference in area, and at the same time air and gas are forced into the igniting-chamber for explosion at the next downward stroke.

In the preceding description of the operation of my improved gas-engine, I have referred to the expulsion of the fully-expanded gases from the lower end of the cylinder 9 without stating where such gases are led, and I have referred to the contents of the upper end of cylinder 9 as being led through pipe 51 to the valve 56 without making any mention of the economizer 46, to which both the pipe 51 and the exhaust-pipe 45 are shown attached in the drawings, and the construction of which was explained in describing the drawings. It is because the presence of this economizer is not necessary to the operation of my engine, while at the same time it is a very desirable adjunct to its efficiency. The drawings show plainly how a certain amount of the heat still contained in the spent gases from the lower end of cylinder 9 may be transmitted through the surface of the tubes 49, which said gases traverse on their way to waste to the contents of the upper end of cylinder 9 on their way from said cylinder through pipe 51, middle compartment, 54, and pipe 55 to the valve 56. The calorimeter of the tubes 49, or, in other words, their aggregate internal cross-section, should exceed considerably the cross-section of the exhaust-pipe 45, so as to avoid causing back-pressure, and it should be noted, also, that the radiating-surface of said tubes should be very ample on account of the low terminal temperature of the gases due to their unusually large expansion in the two cylinders.

An important advantage of my engine lies in the absence of water-jackets in contact with or in proximity with that portion of the cylinder-walls in which the expansion of the burned gases takes place. Such a disposition is made possible by the use of the loose plunger 19 and the packing 20. As the plunger 19 does not touch the walls of the cylinder 18, it is obvious that no cooling of the walls of said cylinder is required. By the time the gases, after being expanded in the high-pressure cylinder, are allowed to further expand in the lower end of the low-pressure one on the return-stroke, their temperature has already fallen sufficiently to make it practicable to run the piston 17 with ordinary packing-rings and to keep them lubricated. The packing 20 around the plunger 19 forms a joint around the said plunger and also between the two cylinders. To run this packing tight without cutting it, I surround it with the water-jacket 22; but this jacket does not extend beyond the packing, and to facilitate matters I make the cylinder 18 and the plunger 19 very long, so that the upper end of the plunger 19, which is the hottest, never enters the packing, even on the lower center, and, in fact, is even at that point some distance above it. By this arrangement, as will readily be understood, and by the thorough jacketing of all exposed surfaces with the non-conducting material 15, no heat is abstracted from the exploded gases, except by expansion—that is, by doing work—and a very great efficiency must be developed from my engine as the natural result of the construction described.

The igniting-valve 58 operates in the following manner: Its eccentric is set, as shown in diagram Fig. 8, later than the crank-pin, so that when the latter is on its upper center at A the valve has still to perform a portion of its upward stroke, represented by the arc *a b* of its eccentric and equal in length to the width of the igniting-port 81. In other words, when the engine is on its upper center the igniting-valve is, as shown in Fig. 2, still on its upward stroke and on the point of opening the port 81 to the port 80 on the seat 97. Before this port closes again it is evident that the valve must travel downward an amount equal to the width of the port 81; or, to put it differently, its eccentric must reach the point A_1, so that the port 81 has been open during a period represented by the arc $a\ b\ a_1$ of the eccentric corresponding to the arc $A\ A_1$ of the crank-pin, (in these drawings about one-quarter of a revolution.) The igniting-valve at this stage has therefore returned to the position shown in Fig. 2, with the difference that it is now on its downward stroke. As it keeps on going down, it opens the port 82 to the chimney-ports 85, so as to purge the three lobes 88, 89, and 90 of the burned gases with which they are filled. As the valve recedes a little farther, the port 83 comes opposite the port 92, and the port 87 comes opposite the port 94, and by the draft of the chimney 60 the flame 95 is drawn through the ports 94 and 87 into the lobe 88. The draft of the chimney 60 also causes air to be drawn from the atmosphere through ports 92 and 83 into the lobe 90, then through the gauze 91 to the lobe 88, hence through the gauze 91 again to the lobe 89, and through the ports 82 and 85 to the chimney 60. The hole 86, however, which is now uncovered to the groove 96 on the reverse face of the valve, allows gas to escape from the supply-pipe 125 and port 126 into the port 92, which gas is mingled and drawn in with the entering air through port 83. When this mixture passes the wire-gauze 91 and enters the lobe 88, it becomes ignited by contact with the flame 95 and burns on the face of the wire-gauze, as shown in Fig. 5. In this Fig. 5 the igniting-valve is shown in its extreme lowest position. As the valve moves up, it successively closes the ports 94 and 92 and the chimney-ports 85, (as well as the port 86;) but the flame still lingers on the gauze 91, and when the port 81 is opened to the port 80 this flame, coming in contact with the explosive charge lying back of the port 80 in the igniting-chamber 27, explodes it instantly. The flame on the gauze 91 is of course blown out by the explosion, and the three lobes of the valve are filled with burned gases. As the valve moves down again, these foul gases blow out at the chimney 60, and gas and air are admitted to relight a flame on the gauze 91, &c., as described above. The combined air and gas admission valve 56 serves to mix the air and gas compressed, respectively, by the compressor end of the low-pressure cylinder and by the gas-pump, and by its construction and its location as close as possible to the chamber 27 it does away with the necessity of having in any part of the engine, except beyond this valve, an explosive mixture of air and gas, as this valve only allows the air and gas to mix in such amounts and at such times as it is required to introduce a fresh explosive charge in the igniting-chamber 27. Reference to the drawings and to the description of this valve given above shows without further explanation how it acts and how the current of air passing through the gauze-tube 121 draws the gas from the annular space 127 through the meshes of said gauze-tube.

I will now describe the operation of the governor and the gas-measuring pump. The object of my governor is to regulate the speed of the engine by varying the amount of gas admitted to the engine for each explosion. This, I am aware, is a feature possessed by other existing engines; but my method and the devices I employ differ, essentially, from any heretofore in use, in the fact that while by all other methods any variation in the amount of gas admitted to the engine must necessarily alter the degree of inflammability of the explosive charge, and therefore make the explosion uncertain or imperfect, the use of my method, while it involves a variation of the amount of explosive charge admitted to the engine, insures by positive means a uniform degree of inflammability to each and every charge. By my method the volume or amount of gas only is varied by the action of the governor; but the relative proportions of gas and atmospheric air in each and every charge, whether large or small, is independent altogether of the fluctuations of the governor, and is made dependent only upon one constant element—viz., the relative displacements of the gas-pump and the air-compressing cylinder. The toe or tappet 67 is attached permanently to some moving part of the engine. In this case it is shown attached to the stem 75 of the igniting-valve. The tappet is shaped so as to come under the piece 102 of the fitting 102 and 103, and its top is composed of a series of steps, I II III IV V, the downward pitch of which is turned toward the governor, and the upper and lower limits of travel of which are represented by dotted lines. The dotted horizontal line through the point of the toe 102 is the line below which this toe cannot fall, no matter how much it may be drawn in by the governor, as when the toe is on that line the valve 111 is closed. The governor-balls are shown close together, which correspond with the minimum speed of engine with full load and maximum admission of gas. The tappet 67 is set so that when the piston 98 of the gas-pump 64 is at half-stroke the step I is on the horizontal line through 102, and in contact with said toe 102. As the piston and the tappet move up, the valve 111 opens; but as the valve 115 is held up to its seat by the pressure in the pump no gas enters the latter. When the pump turns its upper center, however, the valve 117 seats and the valve 115 opens, thereby admitting gas from the supply through the chambers 112 and 113, the valve 111, and the ports 114. If we assume that the outer circle in Fig. 8 represents the path of the gas-pump crank or eccentric, (which is synchronous with the main crank,) while the inner one represents that of the igniter-eccentric, then we see that when the pump reaches the upper center at A the toe 67 is at a position corresponding to *a* and still moving upward. When the crank reaches mid downstroke at A_1 the tappet 67 is at a position corresponding to *a*, and, as said above, its step I reaches the horizontal line through 102, Fig. 10, and the valve 111 becomes closed. It follows then that gas was admitted during the first half of the downstroke of the gas-pump. (If desired, the admission could be made to last a little longer by a different setting of the tappet 67. In other words, the maximum charge may be regulated at will.) After the tappet 67 has fallen below the line 102, and the valve 111 has closed, a partial vacuum is formed in the gas-pump during the second half of its downstroke, which vacuum is taken up again during the first half of its up or return stroke, so that when the pump-piston 98 reaches half-stroke on its way up the gas has recovered its admission-pressure. During the first half of the upstroke the piston 17 has been compressing air, and it follows that the air-pressure in the compressor end of cylinder 9 is greater at mid-stroke than that pressure of the gas in the gas-pump—in other words, that while the air and gas pistons are synchronous the former has the lead over the latter in the point of pressure. It follows, also, that when further in their upward stroke the air-pressure is sufficient to overcome the pressure in the igniting-chamber 27 and cylinder 18, and therefore the air passes into said igniting chamber and cylinder through the valve 119, another portion of the stroke must elapse before the same pressure is also reached in the gas-pump, and only when this occurs can the valve 120 open and gas be admitted with the entering air to the chamber 27. From the point where the gas begins to enter as the two pistons of the air and the gas pumps are moving together, and as the pressure in both pumps is the same, the relative amounts of gas and air introduced into the chamber 27 depend solely upon the relative displacements of the two pumps. It becomes evident, therefore, that even with the maximum admission of gas before any of the gas can possibly enter the igniting-chamber 27 a certain amount of pure atmospheric air must have entered first. If the speed of the engine increases, causing the governor-balls to fly out, the piece 103 slides in the head 104, and the toe 102 is drawn in toward the governor. It follows that this toe 102, instead of coming opposite the step I of the tappet 67, comes opposite a lower step, say, for illustration, the step III, and this step III being lower than the step I will let the valve close before the pump-piston has reached the middle of its downward stroke. The admission being closed sooner—we will say, for example, at quarter-stroke—the pump-piston will draw a partial vacuum for the last three-quarters of its downstroke and take it up during the first three-quarters of its upstroke, the compression of the gas above its admission pressure only, beginning with the last quarter of the upstroke. In the meantime the air-compressor has been compressing since turning the lower center, and the lead of the pressure therein over that in the gas-pump is proportionately larger than it was with maximum admission of gas, so that the time at which the entering pressure is reached in the gas-pump is postponed until a proportionately later period of the stroke. When this pressure is reached in the gas-pump and only then does the valve 120 open and gas mingle with the air; but the amount of gas in proportion to the air is the same as it was with full admission. In other words, in this case a larger volume of pure air entered the igniting-chamber 27 before any gas was admitted, and the introduction after that was of gas and air for a smaller period, but in the set proportions determined by the displacements of the gas-pump and the air-compressor. As many steps are provided as practice may indicate. The last step (V in this case) is set so that it does not reach the horizontal line drawn through the point 102. Therefore when the speed of the engine is such that the governor draws the point 102 opposite the last step no gas at all is admitted, and an explosion is missed on the following downstroke. Owing to the high expansion provided for in my engine it might happen that when an explosion is thus missed the charge of compressed air alone thus used might be expanded below atmospheric pressure in the low-pressure cylinder, causing a partial vacuum therein, and thereby checking the engine to an undersirable extent. A shifting-valve would naturally suggest itself, but it would be useless, as reference to the drawings will show that if such an occurrence should take place the construction of the engine automatically affords the relief required. If a vacuum should form in the lower end of cylinder 9 on its upstroke, air would be admitted to it at once from the atmosphere through piston-rod 8, ports 23, core 24 of piston 17, valves 26, upper part or compressor end of cylinder 9, port 132, pipe 51, valve 119, chamber 27, port 28, cylinder 18, port 33, recess 37 in valve 29, and port 34, and even if a vacuum should form as early as in the downstroke of plunger 19 the relief would be given automatically in the same way.

The diagrams Fig. 16 show without being to any scale the results of my governing method. Forty pounds is the pressure which we will assume it requires to enter the igniting-chamber 27. The air-compressor reaches this pressure at a period, *a*, from the end of its stroke, and does so at each and every stroke, forcing at that point a certain stated volume of air in the chamber 27, regardless of the variations in the speed of the engine. With the maximum admission of gas to the pump (half-stroke in this case) the gas-pump reaches the entering pressure at a period, *c*, from the end of its stroke, so that the charge in the explosive-chamber will consist of a portion of pure air not mixed with gas, which entered first, and a portion uniformly mixed with gas throughout lying near the igniting-valve, the former corresponding in volume to A—C, and the latter to *c*, the degree of inflammability of the mixture being regulated once for all by the relative displacements of the gas-pump and the air-compressor. The mixture is indicated by all that portion of the igniting-chamber diagram which is cross-sectioned. The part left white is pure air, and the gas can never enter that part, as that was put in the igniting-chamber before the gas, even at maximum admission, had reached sufficient pressure to enter. To better illustrate the case, this diagram also shows the working of the pump at half-admission—viz., shutting off the gas at quarter-stroke, a vacuum is formed for the last three-quarters of the downstroke, is taken up during the first three-quarters of the up or return stroke, and compression above admission pressure begins with the last quarter. The volume of gas forced in by the gas-pumps corresponds to *b* in this case. The volume of air is represented as under all circumstances by *a*. It follows that a volume *a*—*b* of pure air first enters the chamber 27 and is followed by a volume corresponding to *b* of mixture of the invariable degree of inflammability. In this case in the diagram of the chamber 27 the pure air is represented by the segment left white plus the segment in single cross-section, while the segment in double cross-section represents the explosive charge. The proportional lines, connecting the air-pump diagram to that of the explosive-chamber are mere construction lines, bearing no relation to the diagrams, except for the purpose of carrying out graphically the proportions of pure air and explosive mixture as measured off the diagrams of both pumps.

It should be noted that my method of regulating the speed of the engine and the gas-pump and its operating devices described in this specification are not confined in their application to the compound type of gas-engines, but may be applied to advantage to any gas-engine of any type whatsoever.

What I claim as my invention, and desire to secure by Letters Patent, is—

1. In a compound gas-engine, the combination of the single-acting high-pressure cylinder, low-pressure cylinder, one side of which operates as an air-compressor, suitable ports, 33, 34, and 35, and slide-valve 29, all substantially as and for the purpose specified.

2. In a compound gas-engine wherein one end of the low-pressure cylinder is used as a compressor, the hollow piston-rod, hollow piston, and inlet-valves 26, through which the fluid to be compressed may be admitted to the end of said low-pressure cylinder used as a compressor, substantially as described.

3. In a compound gas-engine constructed as described above, the port 38, opening to the port 33, and the pipe 39, leading to the storage-tank or receiver 44, with the intervening check-valve 40, for the admission of the compressed air or products of combustion from the cylinder 18 to the tank 44, substantially as specified.

4. In a compound gas-engine, in combination with the ports 38 and 33, pipe 39, receiver 44, check-valve 40, the by-pass pipe 42, and valve 43, substantially as and for the purpose specified.

5. In a compound gas-engine constructed as described above, the combination, with the single-acting high-pressure cylinder 18 and low-pressure cylinder 9, one end of which acts as an air-compressor, of the gas-pump 64, substantially as described.

6. In a gas-engine in which the two elements of the explosive charges are compressed in separate pumps, and in which the air-pump displaces a uniform volume of unmixed air at each stroke, a gas-pump, the supply of gas to which is shut off at varying points of its outstroke, according to the variations of the speed of the engine, substantially as and for the purpose set forth.

7. In a gas-engine in which the two elements of the explosive charges are compressed in separate pumps, and in which the air-pump displaces a uniform volume of unmixed air at each stroke, a speed-governor controlling a gas-supply valve to the gas-pump in such a manner as to close said valve at varying points of the outstroke of said pump, substantially as and for the purpose specified.

8. In a gas-engine in which the two elements of the explosive charges are compressed in separate pumps, and in which the air-pump displaces a uniform volume of unmixed air at each stroke, the combination, with a gas-pump provided with suitable automatic inlet and outlet valves, and a separate gas-supply valve on the gas-supply, of a speed-governor operating said valve and causing it to close at varying points of the stroke of said pump, according to the fluctuations in the speed of the engine, substantially as described.

9. In a gas-engine, in combination, the gas-pump 64, governor 66, bearing 105, shaft 106, with head 104, fitting 102 103, link 100, arm 107, valve 111 on the gas-supply to the pump, and tappet 67, with steps I II III IV V, all being operated and connected substantially as and for the purpose specified.

10. In a gas-engine, the T-shaped combined air and gas admission fitting 56, provided with air-valve 119, gas-valve 120, and sleeve of wire-gauze 121, all substantially as and for the purpose specified.

11. In a gas-engine, a seat for the slide igniting-valve cast off the wall proper of the

igniting-chamber by means of lugs or distance-pieces allowing for a circulation of air to cool off said seat, substantially as described.

12. In a gas-engine, the deflecting-plate 78, set at right angles to the entering charge, and held in position by means of the lugs 79, between which the charge is compelled to pass and receives a rotary motion, substantially as described.

13. In a gas-engine, a slide igniting-valve made in two portions, secured with an intervening sheet of wire-gauze, 91, so as to form the three chambers 88, 89, and 90, substantially as described.

14. In a gas-engine, a slide igniting-valve held to a seat, 97, on which are the igniting-port 80 and the relighting-port 94 to the burner 95, by a spring-pressed backing-plate, 59, on which are the vent-ports 85, the chimney 60, the gas-supply port 86, and the air-supply port 92, said valve being made in two sections, with the intervening gauze 91 forming the chambers 88 with ports 81 and 87, 89 with port 82, and 90 with port 83, all connected and operated substantially as described.

15. In a compound gas-engine constructed as described above, the combination of an economizer, 46, with the exhaust-pipe 45, and the pipe 51, leading from the compressor end of the low-pressure cylinder to the admission-valve 56, substantially as described.

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Witnesses:
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