P. K. STERN.

THERMODYNAMIC MOTOR.

APPLICATION FILED NOV. 19, 1900.

975,651. **Patented Nov. 15, 1910.**

5 SHEETS—SHEET 1.

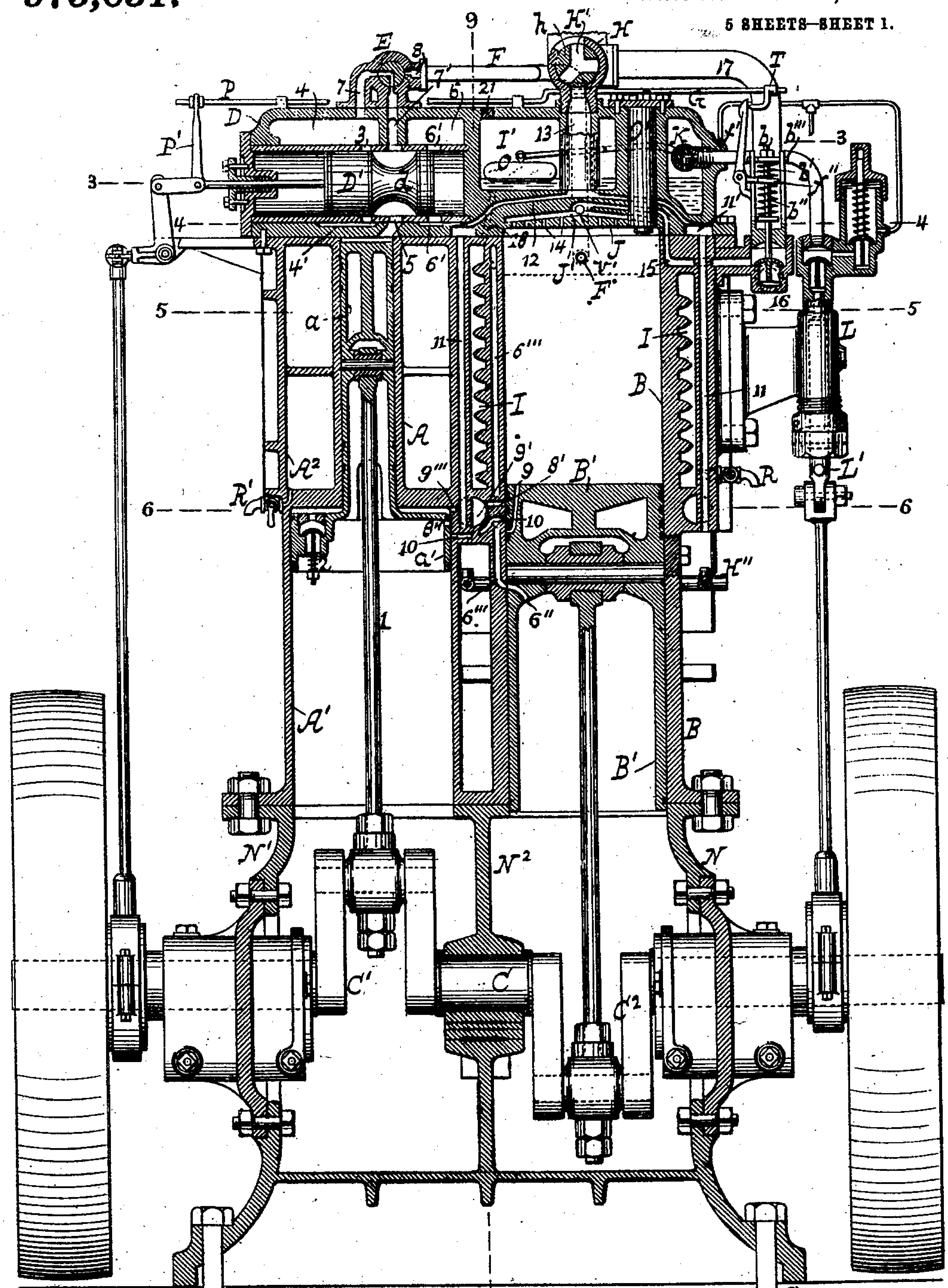

Fig. 1

Witnesses

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5 SHEETS—SHEET 2.

Fig. 2

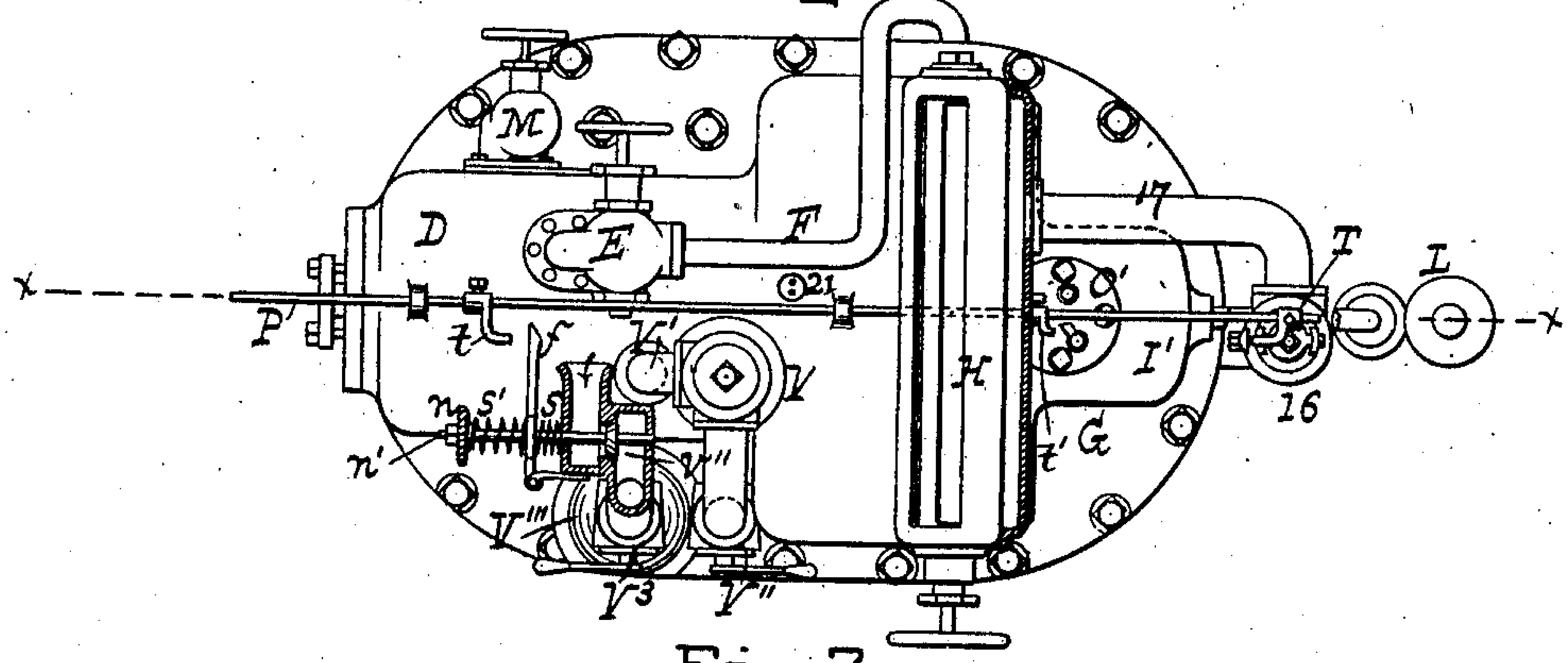


Fig. 3

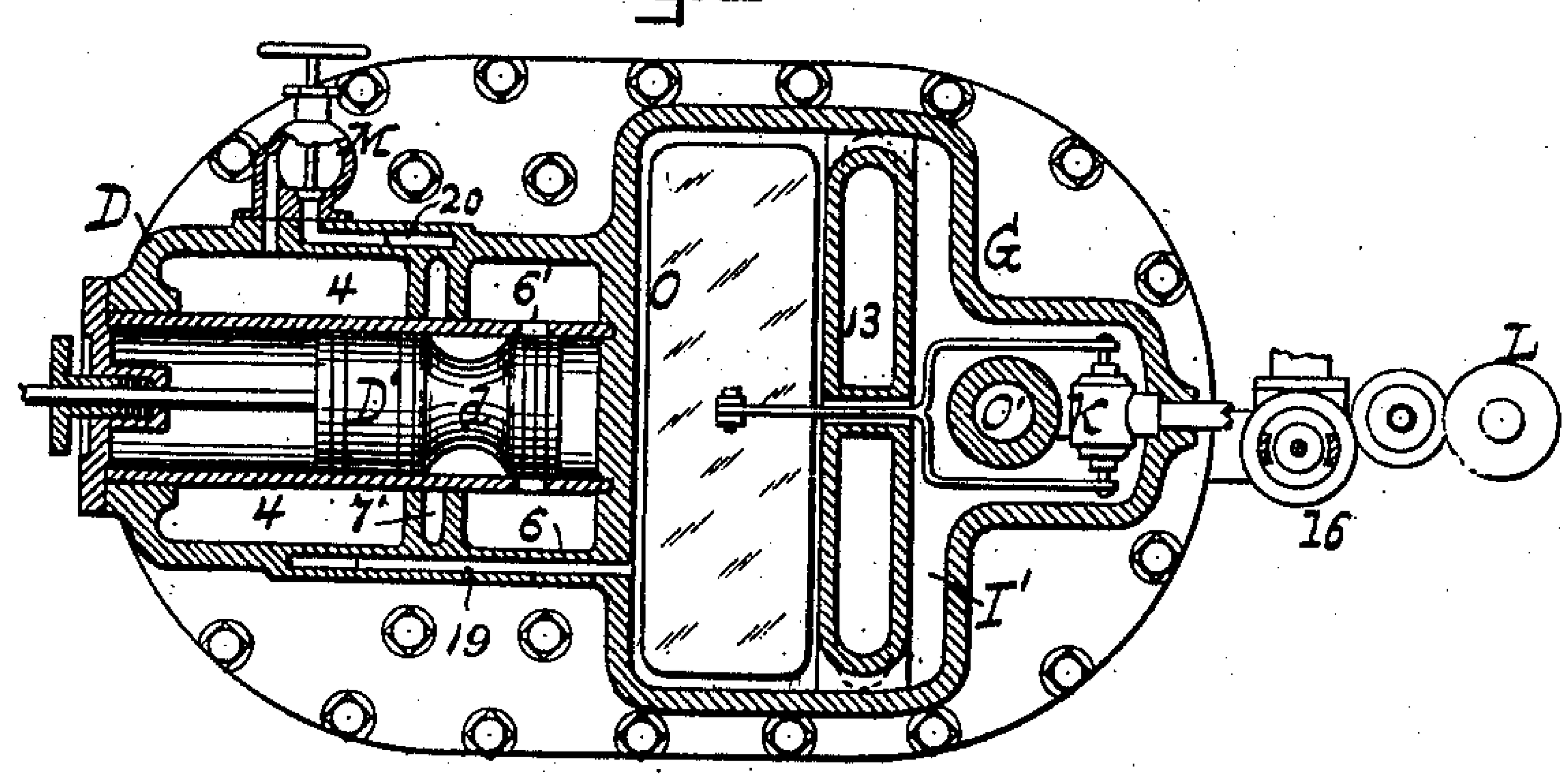
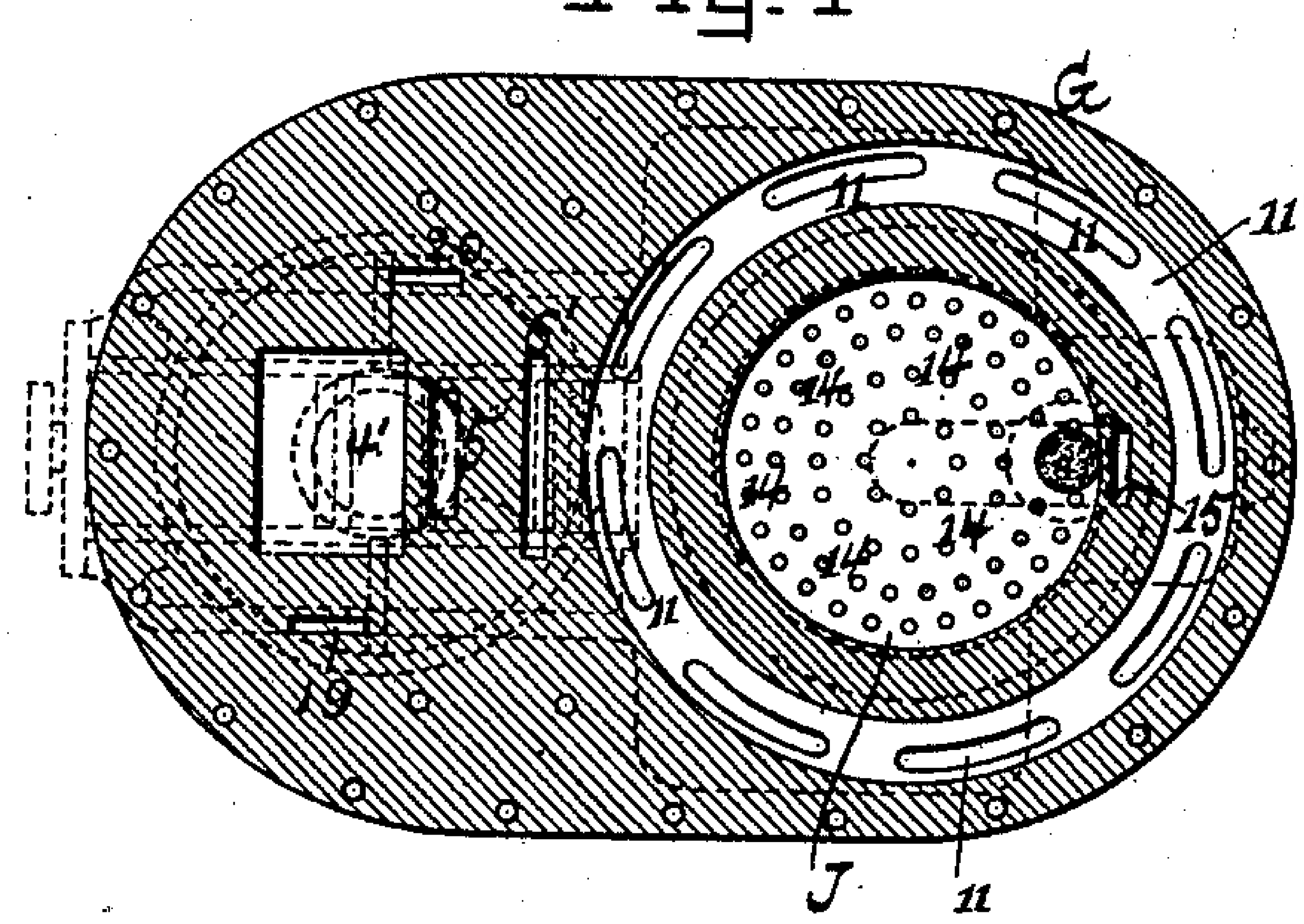


Fig. 4



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5 SHEETS—SHEET 3.

Fig.5

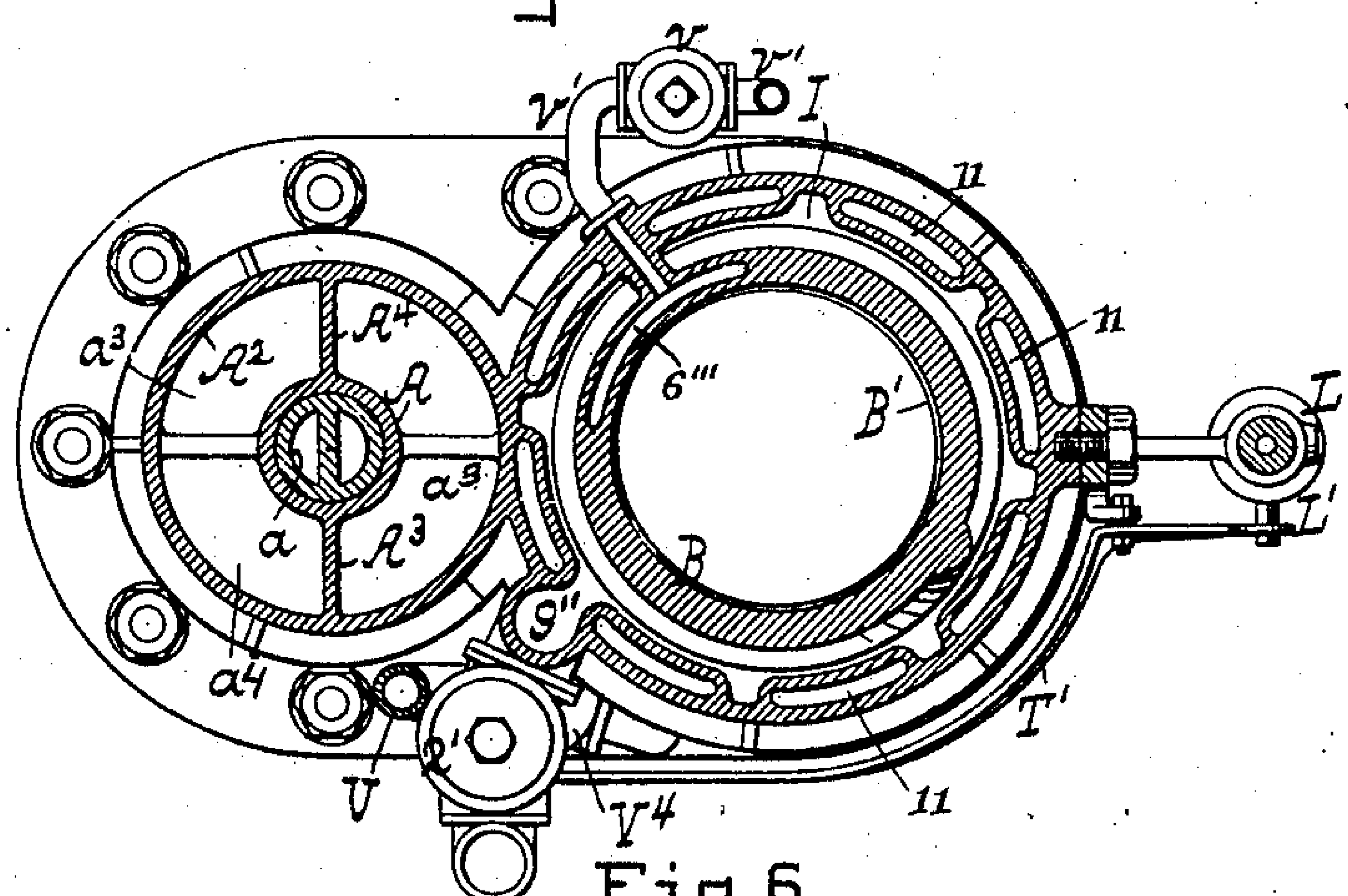


Fig.6

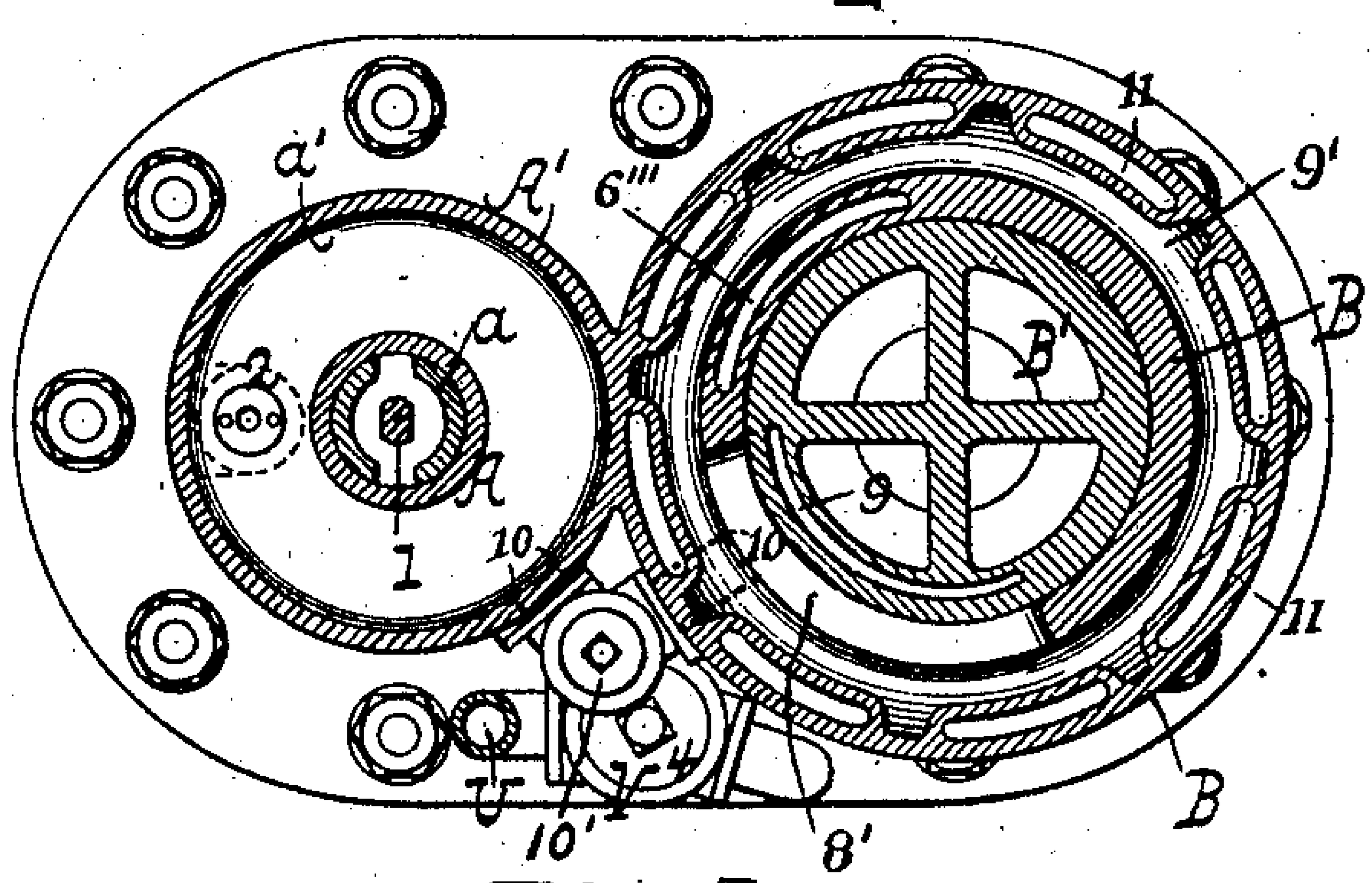
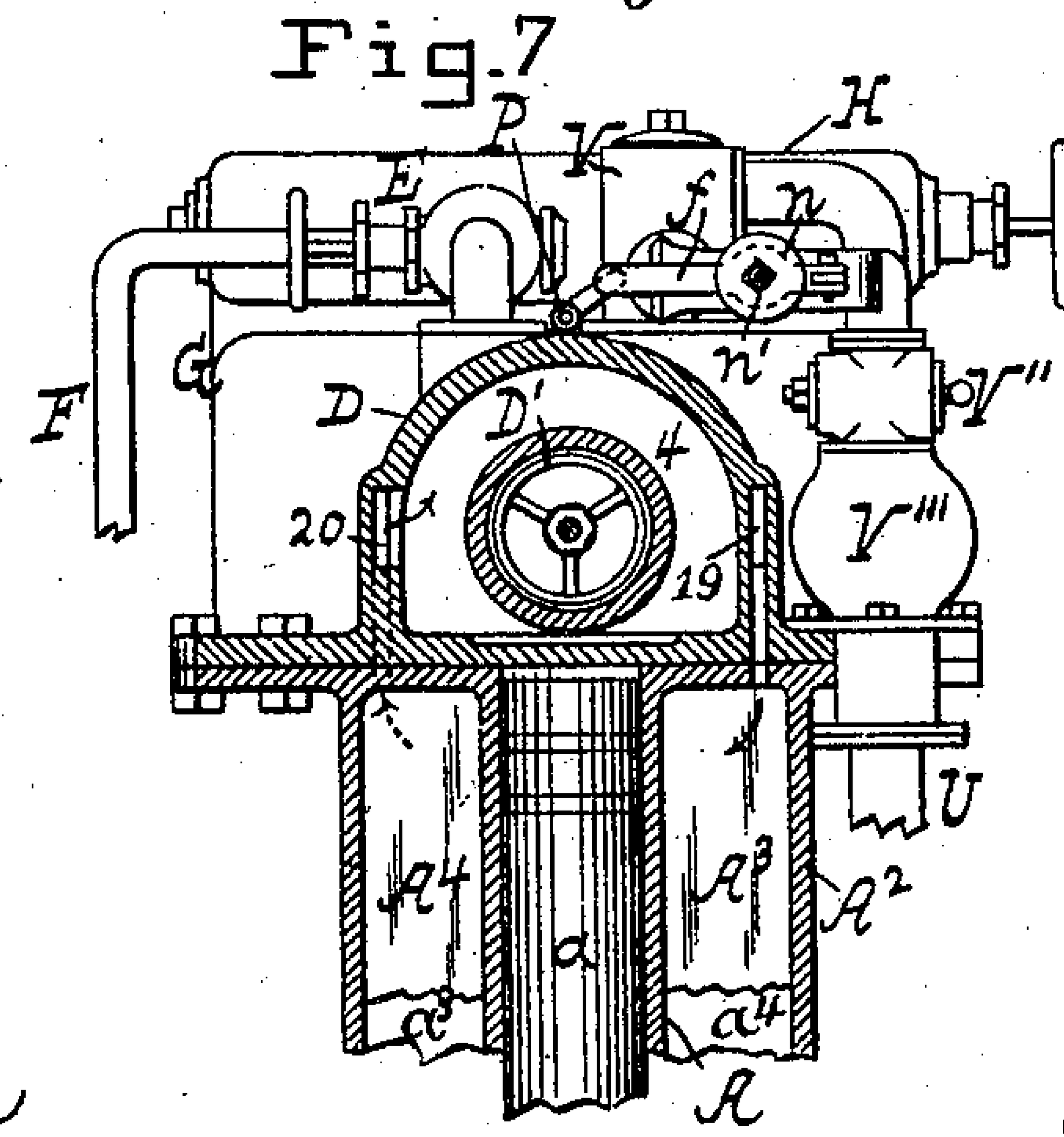


Fig.7



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5 SHEETS—SHEET 4.

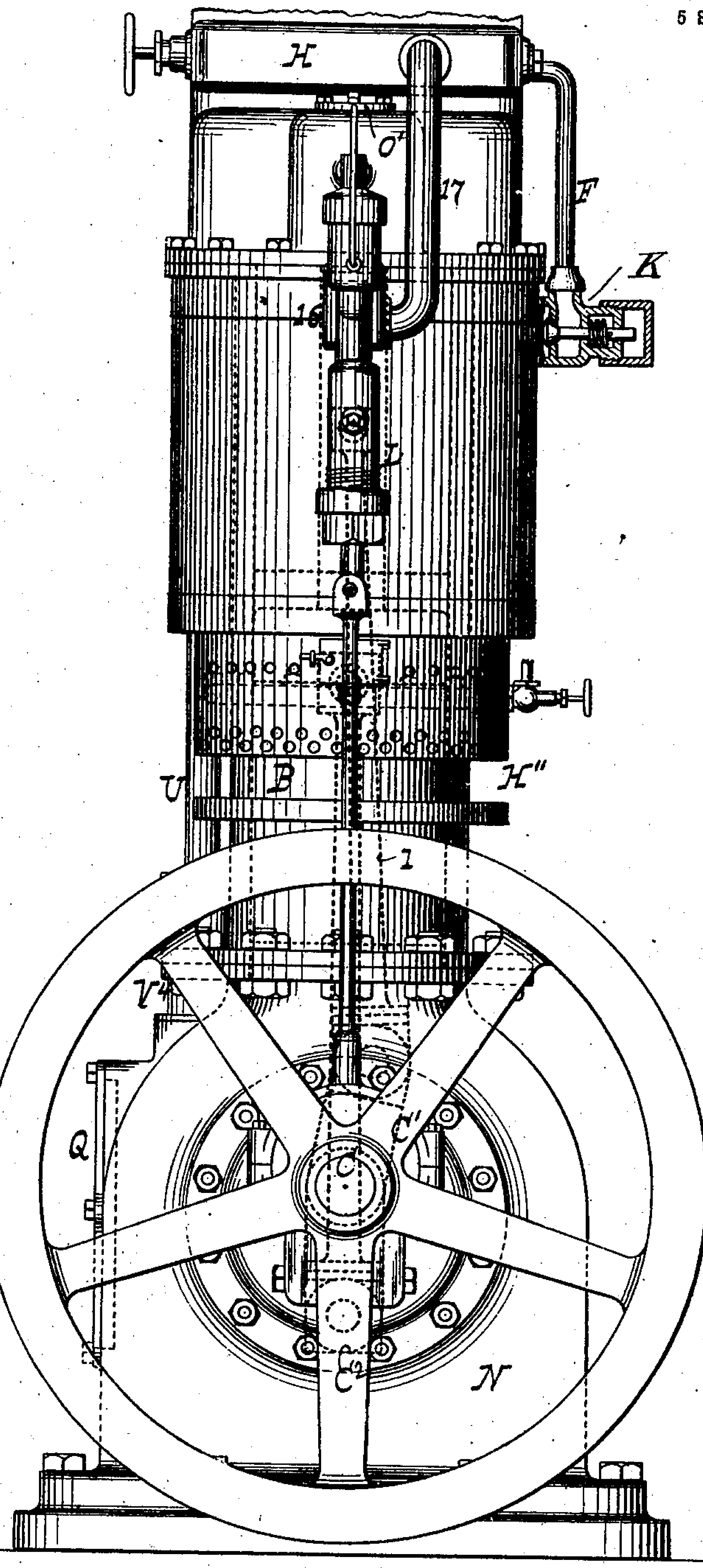

Fig. 8

Witnesses

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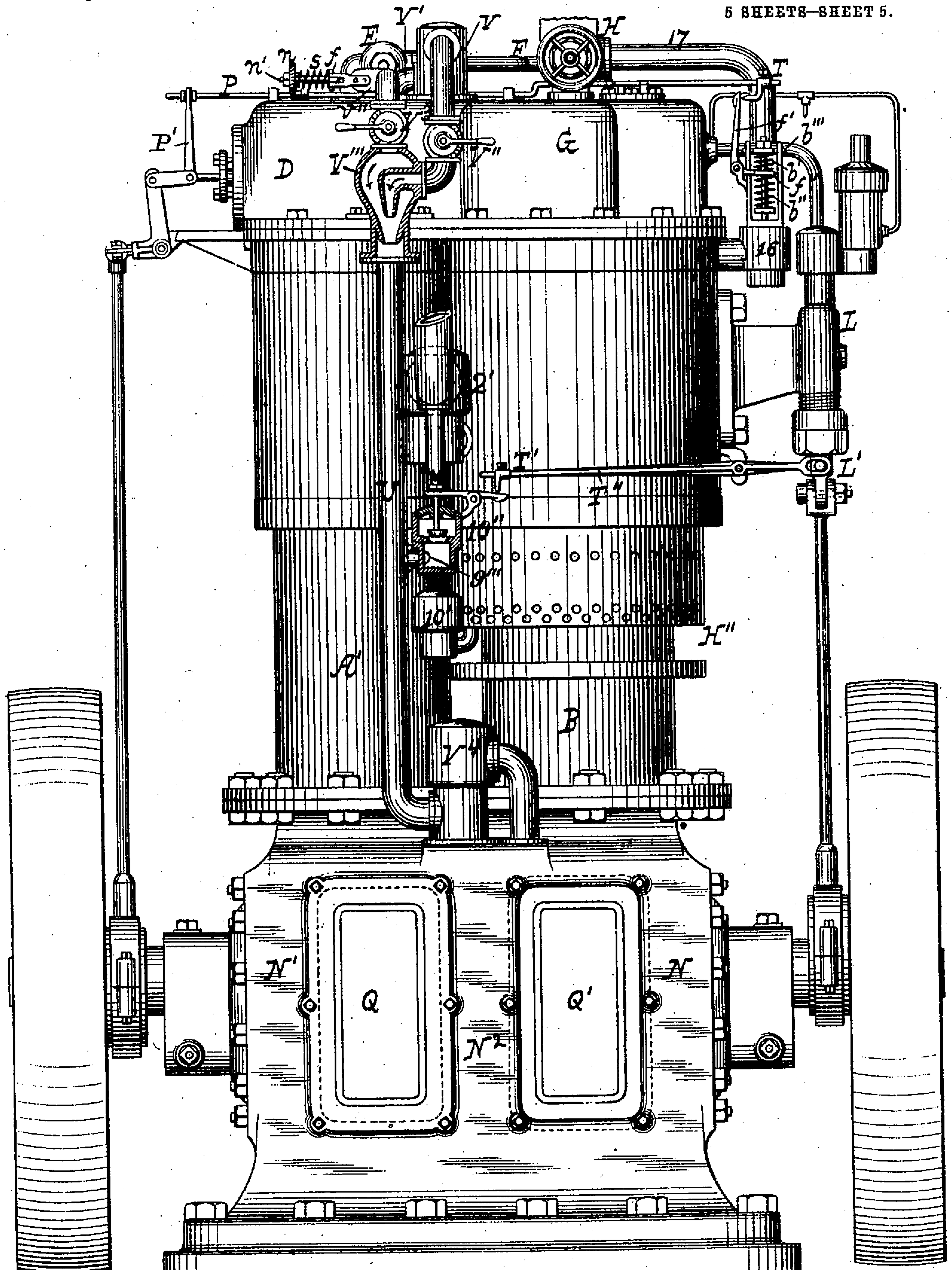
5 SHEETS—SHEET 5.



Witnesses

Chas. Wahlers

Abraham J. Spiro.

Fig. 9

Inventor

Philip K. Stern

UNITED STATES PATENT OFFICE.

PHILIP K. STERN, OF NEW YORK, N. Y.

THERMODYNAMIC MOTOR.

975,651. Specification of Letters Patent. **Patented Nov. 15, 1910.**

Application filed November 19, 1900. Serial No. 36,993.

To all whom it may concern:

Be it known that I, PHILIP K. STERN, a citizen of the United States, residing at the city of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Thermodynamic Motors, of which the following is a specification.

My invention in thermodynamic motors relates to a new class of heat engines wherein the power medium is used dually, being employed both as a conveyer of the energy and as a fuel for supplying the energy for operating the engine, in a manner whereby when it is employed to perform the mechanical work of the engine by the expansive property it possesses when confined, due to its sensible heat, it is also used to further perform the mechanical work by the expansion due to the heat of chemical combination by combustion.

My invention has, therefore, reference to a thermodynamic motor embodying both that class of heat engines known as expansive engines and that class commercially known as explosive engines, and inasmuch as that the fuel employed in explosive engines utilizes the heat of chemical combination to perform the mechanical work of the engine, and the so-called expansive engines, usually steam or vapor engines, perform their mechanical work by the sensible heat contained in the vapor, I prefer to distinguish the two classes of engines by the usual commercial method of expression. terming the steam or vapor engine an expansive engine, and the ordinary commercial gas engine an explosive engine, although both types of engine are operated by the expansive property of the power medium. I mean by power medium either a carrier of energy in the form of vapor, which, when sufficiently heated furnishes the necessary energy for operating the engine, in which case the power medium gives up its energy to the piston of the engine and by virtue of its expansive property transforms the sensible heat of the vapor into mechanical work, or a producer of energy in the form of some combustible volatile liquid which when heated by its chemical combination with another ingredient becomes a power medium, in which case the said vapor is transformed in a power medium by virtue of the expansive property of the heated gases contained in the chemical combination.

With this method of interpretation, my invention relates then, to a new class of heat engines or thermodynamic motors, wherein the power medium is used both expansively and explosively.

As my invention relates to the transformation of the kinetic energy of a power medium by both the direct and the indirect methods of utilizing the potential energy of the fuel to this end, I have preferred to designate the combination of these two methods when employed in the operation of a motive power apparatus, a thermodynamic motor.

In heat engines of the explosive type which have come to my notice, the refrigeration necessary in consequence of the excessive heat developed by the combustion of the explosive mixture within the cylinder, was accomplished by the use of some heat-absorbing medium, such as water contained in a receptacle surrounding the cylinder, or by a series of radiating disks or rings secured to the cylinder, between which air was disposed so as to perform the function of the heat carrier; while in some cases it has been suggested to use a volatile refrigerating liquid whereby the excessive cylinder heat may be employed to produce mechanical refrigeration, and the water that would have been used in lieu of the refrigerating liquid for cooling the cylinder, is used for taking up the heat of the refrigerating liquid. In any of these methods, however, the heat carried off by the water-jacket or radiating surfaces dissipates and wastes about forty per cent. of the heat available for performing the mechanical work of the engine.

In thermodynamic transformation of the second order, *i. e.*, where heat is communicated to a power medium such as water or other volatile liquids and the heat of the vapor taken up by the motor in the performance of mechanical work, there is a considerable leakage as it were, or more properly stated, a dissipation of a large percentage of the heat-units which is not made available in the process of evaporation and by the development of mechanical work by the expansion of a liquid into a vapor, there is but a fraction of the heat of the fuel consumed in the vapor generator transformed into mechanical work of the engine.

As a counter distinction between the indirect process or that just mentioned and the direct process, or that wherein the combustion of the fuel develops by the expansive force of the chemical combination of the gases within the cylinder of the motor, a motive power which impels the piston against the resistance of it load, I shall designate the motor operated by the indirect process an expansion engine and the process which the heated power medium undergoes the expansive process while the direct process of transforming the heat into mechanical motion, I shall term an explosive process and the engine developing work through such a process will be referred to hereinafter as an explosive engine. It is well known in the art that the dissipation of heat in developing mechanical work by the expansive process of a power medium is much more excessive than when the mechanical work is developed by the explosive process of the combustibles.

It is the object of my invention to so construct a thermodynamic motor as to combine these two methods of transforming heat into mechanical work, so that the heat of the explosive type of heat engine, which is not all available in practice, may in part be applied so as to perform mechanical work by the expansive process, and by this method of blending the two distinct processes of transforming heat into mechanical work in the operation of one machine, the vapor generator for the expansive engine and the cooling-jacket for the explosive engine are combined, and these two distinctive methods, which have heretofore been separate and independent adjuncts to the development of motive power, are so combined in one thermodynamic motor by my invention, as to provide for the one, by the other, what either is lacking. The manner in which I have carried out my invention to this end is to construct a thermodynamic motor dually, whereby the expansion portion takes up energy from the explosion portion, and the explosive portion takes up energy from the expansion portion, in thermodynamic transformation, and in a manner so as to interchange what would be when considered independently the respective heat losses of each section from one portion to another so as to be turned into useful work at the crank-shaft of the thermodynamic motor.

I have given preference to the use of a vapor of an inflammable liquid rather than to the evaporation of water for the power medium, for the reason that when it is used expansively to develop work by the sensible heat which it contains when heated by the heat due to combustion in the explosive portion, it may be used as an ingredient of the explosive mixture in the cylinder of the explosive portion. This might be accomplished by employing water and evaporating it into steam, and then using the steam in a superheated state as an ingredient of the explosive mixture, but as steam would not be as volatile as some of the forms of hydrocarbon, and therefore would not relieve the explosive cylinder sufficiently of its excessive heat, as well as not being capable, in itself, of furnishing fuel for the explosive mixture, I have given preference to a hydrocarbon liquid fuel for operating my improved heat engine. After the vapor has given up its energy to the working piston and is then exhausted, a considerable amount of heat is carried off by the exhaust, which, being at a lower pressure than that which can be utilized in the transformation of heat into mechanical work, is thrown out into the atmosphere or into a condenser and dissipated, just as the surplus heat generated by the combustion of the explosive mixture in the cylinder of an explosive engine is carried off by the water-jacket or radiating surfaces depending from the cylinder of the engine.

In constructing a thermodynamic motor according to my invention, the exhaust from the expansive portion is taken into the cylinder of the explosive portion and the heat contained in the exhaust vapor is utilized in increasing the activity of chemical combination of the gases employed in the explosive process, and, reciprocally, the surplus heat which is developed in the cylinder of the explosive portion is transmitted to the liquid, thence to the cylinder of the expansive portion. Thus by this interchange, the heat whch would otherwise have been wasted is employed usefully. I consider this feature a distinct advance in the application of thermodynamics to motive power development, and of considerable advantage to the art to which my invention pertains.

Another object of my invention is to provide a means of more completely clearing the cylinder of the explosive portion of the products of combustion than has been attained in the older forms of gas engines and those in vogue at the present time and previous to my invention.

Another object of my invention is to provide a means for increasing the efficiency of the explosive portion by increasing the compression of the mixture prior to ignition. This feature of my invention I accomplish by the provision of a mixture weak in atmospheric air and raising its temperature by compression until it may be as readily ignited as mixtures rich in atmospheric air at a lower compression.

The different features of my invention are fully illustrated in the drawings and described clearly in the subject matter of the specification, and finally more particularly pointed out in the claims.

In the drawings in which I have illustrated the different features of my invention, I have preferred to describe a vertical or upright form of thermodynamic motor combining the expansive and explosive methods of operation, by means of a single-acting single-cylinder expansive type of heat engine, and what is known as a two-cycle explosive gas engine, constructed according to my invention in the aforesaid manner is shown in the drawings, of which—

Figure 1 is a vertical sectional view taken on the line X X of Fig. 2. In this view I have so disposed the parts as to show the entire construction of the motor and all of its details, though in practice the position of the different valves shown may be considerably varied for the sake of convenience. Fig. 2 is a top plan view of my improved thermodynamic motor, looking down upon the cylinder heads and vapor chests. Fig. 3 is a horizontal sectional view taken on the line 3 3 of Fig. 1, so as to show the vapor chest of the expansive portion, the top portions of the vapor chest, and the other working parts which are inclosed in the upper part of the motor. Fig. 4 is a transverse sectional view taken from Fig. 1 on the line 4 4, so as to show the passage ways and ports more clearly; those which I have shown in Fig. 1, where they are not taken in section, by dotted lines, are illustrated in this figure. Fig. 5 is a transverse section taken on the line 5 5 of Fig. 1, showing the tempering flues of the explosive portion, the vapor jacket of the expansive portion, and the exhaust connections of both the expansive and explosive portions. Fig. 6 is a transverse section taken on the line 6 6 of Fig. 1, to more clearly illustrate the exhaust drum. Fig. 7 represents a cross-section of the vapor-chest and a portion of the small expansive cylinder and vapor-jacket. Fig. 8 is a side elevation of my improved thermodynamic motor, looking at the end of the crank-shaft so as to show the angle of centers of the connecting-rods and the different working parts of the motor from that point of view. Fig. 9 is a front elevation of the motor, showing a section of the air and vapor mixer and scavengering valve, and the pipe-connections and valves of the motor from that point of view.

The explosive side of the motor is that to the right of the line 9 9 in Fig. 1, the expansive side being to the left of this line.

In order to designate similar parts I employ similar characters of reference throughout the several views.

The cylinder A is cast integral with an enlarged or trunked extension A′ so as to form a second cylinder. I have shown in the drawings a proportion between the small cylinder A and the cylinder B of about one to nine. That is to say, the small cylinder A has a cross-section of about one-ninth of the cross-section of the explosive cylinder B, that is, one-third of the diameter. The object in this diminution in the size of the expansive section is to obtain the greatest economy commensurate with the efficiency of the expansive and explosive combination at that vapor pressure which it is considered most practical to employ for operating the motor and burning up the exhaust of the expansive cylinder in the explosive cylinder. This pressure must be the result of the proper adjustment of the conditions which depend upon (1) the physical properties of the liquid to be evaporated, (2) the rate at which the small piston will be turning the heat of the vapor, which is received from the products of combustion of the explosive portion through the cooling-jacket, into mechanical work, (3) the quantity of inflammable vapor rejected after expansion to be used in the explosive cylinder, (4) the practical limit of expansion for the vapor, and (5) the limit to which the vapor can be heated in the cooling-jacket so as not to have too high a temperature for the explosive cylinder. The vapor capacity of the expansive cylinder is determined, then, by these considerations, which establishes a proportion between the two cylinders in their respective capacities of about one to nine, as already stated.

Within the cylinder A a piston *a* of the plunger type is employed to operate the connecting-rod 1 in the usual manner for single-acting engines, so as to drive the crank-shaft C by the crank C′. The plunger or piston *a* has an enlarged or trunked end *a*′, which, when working in the cylinder A′, is arranged so as to form, together with the cylinder A′ and check valve 2, an exhaust-pump for scavengering the residual of the products of combustion left in the cylinder B after exhaustion. The check-valve 2 is employed to open the outlet for the air contained in the cylinder A′ when the piston *a*′ is descending, and which closes when the piston *a*′ is ascending. Another check-valve 2′, shown in Figs. 5 and 9, is secured to the exhaust outlet 9″ of the exhaust-drum 9′, and is connected up with the check valve 10″ by a pipe 9^3, so as to relieve the compression of the atmosphere or gas within the clearance space between the top of the piston *a*′ and the adjacent end of the cylinder A which takes place when the piston *a*′ is ascending.

It will be well here to state prior to a general understanding of the details of the motor, that the construction is such as to provide for the two cycle explosive portion of the motor, a means for preventing the escape of fuel from its crank chamber into the exhaust as is customary with the usual type of two cycle motors of this character when the fuel is being transferred from the crank chamber to the combustion chamber during a downward movement of the piston. Provision is also made against the forcing of the fuel from the combustion chamber out of the exhaust at the initial of the compression stroke.

In order to accomplish the effectual reservation of the fuel to the confines of the combustion chamber, I have arranged controlling valves which operate in a manner to effect a reduction of the pressure of the gases in the combustion chamber whereby the same shall be less than atmospheric pressure when the piston B′ is in any of the positions to effect a register of the port 9 with the port 8′ or 10 either on an inward compression or an outward working stroke, and to this end I have arranged the said valves in a manner whereby they will be opened during the operation of the motor against an adjustable and variable resistance and which resistance is adjusted to balance the required pressure for the combustion chamber. The expedients preventing the escape of the fuel in this manner and their function will be more particularly referred to in the following description relative thereto.

The vapor-chest D having the usual piston-valve D′, admission ports 3, main vapor-space 4 and 4′, inlet ports 5, exhaust-space 6 and exhaust port 6′, is employed to control the expansive vapor which impels the piston a' downward in its working stroke. The piston-valve D′ is moved by the ordinary well-known valve-gear controlled by a shaft-governor, which regulates the lap and lead of the valve by the speed of the crank-shaft. This valve-gear also serves to operate the tappet-rod P, which carries the various tappets, which will be explained hereinafter, for operating the fuel control and air valves and ignition plug of the explosive engine. The tappet-rod P is rigidly connected by a bracket or arm P′ to the stem of the valve D′. In the character of governor referred to the eccentric on the crank-shaft which drives the valve-rod, is shifted by a weight, upon variations taking place in the speed of the crank-shaft so as to alter both the lap and the lead of the slide-valve. As these governors are so well-known in the art, I have considered it unnecessary to show any special construction in the drawings, and consequently have omitted the details from the different views.

The cylinder A is surrounded by a jacket A^2 which serves the purpose of both a dry-vapor drum for furnishing vapor to the cylinder A through the vapor-chest D and valve D′, and also a means to prevent the loss of the sensible heat of the working vapor by condensation. In order to separate the dry vapor from that in which condensation is liable to take place, I cast or otherwise form the longitudinal ribs A^3 and A^4 with the cylinder (see Figs. 5 and 7), so as to run from the head end downward almost the full length of the jacket, thus dividing it into two sections a^3 and a^4 after the manner of a steam separator.

E is a three-way cock adapted to register with the vapor-space 4 by a port 7, and with the neck d of the piston-valve D′ by a port 7′. The cock being in the position shown in Fig. 1, the vapor is about to enter from the vapor-space 4 through the ports 7 and 7′ into the small cylinder A by the port 5 around the neck d of the valve D′. When the cock E is turned in a direction so as to register with the ports 7′, and 8, communication will be established with the cylinder B by the pipe F. The object of this three-way cock is to admit of the turning on of the vapor to either one of the cylinders A or B at will, so that in starting up the engine, vapor may be turned on so as to enter that cylinder having its piston, connecting-rod and crank off from the line of dead center. The exhaust port 6′ and the exhaust space 6 are connected by a lateral extension of the port 6′, that is to say, the said port follows the contour of the valve D′, as shown more clearly in Fig. 3. The exhaust space 6 has communication by means of a pipe V′ with a vapor check-valve V (shown in Figs. 2, 7 and 9) located on the cylinder-head G; and from the delivery of the check-valve V the exhaust vapor passes through an indexed hand-controlled valve V″, thence through an elbow, to a mixer V‴, where it is mixed with atmospheric air, the mixture then being carried by a pipe U through a check-valve V^4 (shown in Figs. 6, 8 and 9) into the crank-box chamber N N^2 of the crank-box N′ N so as to enable the explosive mixture to enter underneath the piston B′ of the explosive portion. A port 9 cored or otherwise formed in the piston B′ so as to register with the exhaust port 8′ of the exhaust-drum 9′ and the scavenger port 10, is brought into communication with these ports alternately when the piston B′ has about completed its outward stroke. The exhaust-drum 9′ is cored or otherwise formed in the body of the cylinder B and has an exhaust outlet 9″, shown in Fig. 5. The port 6″ formed in the piston B′ is adapted to admit the explosive mixture from the crank-box chamber N N^2 to the upper end of the cylinder B by way of port 6‴, connecting-pipe v', back-pressure check-valve v (shown in Fig. 5) and perforated plate J when the port 6″ of the piston B shall register with the port 6‴. The port 6″ is to one side of the port 8′ or 10, so that when the piston B′ is in motion, the port 6″ will not register with any of the ports except 6‴, which is indicated by the break in the continuity of the port 6‴ in Fig. 1. The relative positions of these ports is more clearly shown in Figs. 5 and 6. By this arrangement of the port 6‴ with respect to the ports 8′ and 10, the fuel under compression in the crank-box chamber N^2 N by the downward movement of the piston B′ will find its escape only through the port 6‴.

The mixer V‴ is more clearly illustrated in Figs. 2 and 9, and the disposition of the puppet air intake valve v'' and its return springs s and s' as the piston B′ is making its inward or compression stroke is also shown in these figures. To adjust the tension of these springs so as to enable the valve v'' to operate with more or less suction by the action of the piston B′ when it is making its inward stroke, and is inducting the charge through the valve v^2 into the crank box chamber N N^2, I arrange a milled head nut n threaded upon the stem n' of the puppet intake valve v''. The two compression springs s and s' are arranged so as to operate together to return the valve v'' to its seat. Interposed between the two springs s and s' is a pivoted lever f pierced so as to admit the passage of the valve-stem n' through it. The arrangement of this lever is such that upon moving it in a direction so as to compress the spring s, the tension of the lighter spring s' will take up the thrust for seating the valve v''. During a long stroke of the tappet-rod P such as would be imparted to it by the action of the governor during a diminution in the rotational speed of the engine, the tappet t, which is secured with a set screw to the tappet-rod P will impinge against the lever f as the valve D′ travels backward or to the right of its position shown in Fig. 1; and by virtue of the tappet t and lever f compressing the stiffer spiral spring s, and leaving only the weaker spring s' to seat the intake valve v'', the intake of the atmospheric air into the valve will be admitted more freely than when the valve D′ is decreasing its stroke whereby the shorter path of action is given to the tappet-rod. That is to say, when the lap of the valve D′ has been decreased. The extent to which the stiffer spring s is compressed by the lever f, therefore depends upon the lap and lead of the valve D′. As the point of cut-off of the vapor to the small cylinder A is also effected by the valve travel, the quantity of vapor exhausted into the exhaust space 6 and into the mixer is varied according to the load, that is, according to the speed of the crank-shaft; consequently the respective volumes of air and vapor mixed is kept constantly at approximately the same ratio, though the total quantity of air and vapor, (that is, the explosive mixture,) taken into the crank-box chamber N N^2 and delivered into the cylinder B behind the piston B′ in a manner as already stated, is varied. For the main adjustments of the volume of air at the intake, I employ an indexed hand-controlled valve V^3 connected to the intake pipes, as clearly shown in Figs. 2 and 9. The indexed hand-controlled exhaust vapor valve V″ and the indexed hand-controlled air valve V are shown with their stems in a horizontal position in the drawings for convenience of illustration. In practice, however, I prefer to place these valves so that their stems will stand in a position so as to avoid the displacement of the adjustment of the valves in consequence of vibration during the operation of the engine. The tempering flues, 11, which are in this example eight in number, are formed in the casting of the cylinder B and disposed circumferentially about the same, as shown in Fig. 5, and register with an annular groove or channel 11′, cast in the cylinder-head G. The cylinder-head G, which is adapted to cover the head ends of the cylinders A and B and contains those parts of the motor located above the line 4 4 of Fig. 1, is a casting carrying the vapor-chest and all of the mechanism which is shown above this line. The manner of securing the head G to the cylinders is more clearly shown in top plan view Fig. 2 and also in Figs. 3 and 4.

Communicating with the annular groove 11′ are the ventilating passages 12, which communicate also with the smoke-flue 13 and three-way cock H. A burner or heater H″ such as is used in ordinary gasolene or gas stoves, is disposed about the exterior of the cylinder B and is so arranged as to have its jets register with the tempering flues 11, as shown in Fig. 1. The disposition of the tempering-flues 11 and the heater H″ is such as to transmit heat to the jacket I so as to heat whatever liquid may be contained therein. When the three-way cock H has its valve h turned into a position so that the port H′ registers with the smoke flue 13, burned gases will pass up through the tempering flues 11 into the annular groove 11′, ventilating passages 12, smoke-flue 13, port H′ of the valve h of the three-way cock H and into the atmosphere.

Formed in the cylinder-head G is the scavengering air-showering device, which consists of a plate J having a multiplicity of small perforations 14, as shown in section in Fig. 1 and in top plan view in Fig. 4. These perforations are so grouped as to spread the air which is taken in through them as to form one continuous air piston when the air is taken in through the cylinder B, which will be explained hereinafter; the disposition of these perforations will be in the meanwhile more clearly understood by reference to Figs. 1 and 4. Communicating with the small perforations 14 is an annular air passage J′, which is formed in the cylinder head G. This is connected with the atmosphere by a passage-way 15, scavengering intake check-valve 16, air supply pipe 17 and three-way cock H, the arrangement being such that when the three-way cock H has its valve h turned into that position shown in Fig. 1, the ingress to the cylinder B will be from the surrounding atmosphere into the port H′ of the three-way cock H, pipe 17 scavenger intake check-valve 16, passage-way 15, annular air passage J′, and perforated outlets 14.

The scavengering intake check-valve 16 has a tubular frame-work which is slotted or cut away so as to admit of the introduction of the arm f'' of the bell-crank lever f' f'', which also forms a guide-way for the cross-head b'''. The check of the valve 16 is held on its seat by the adjustable compression springs b' and b'' acting on the valve-stem b by a fixed collar on the stem b and against the underneath side of the adjustable sliding cross-head b''' which takes the upward thrust of the springs and is adjusted by a nut threaded to the stem b as shown in Figs. 1 and 9, the arrangement being such that upon turning the nut in one direction, the cross-head b''' is forced down so as to create a comparatively greater pressure, thereby preventing the valve from opening under a light pressure, and upon turning the nut in the opposite direction, the compression on the springs will be released so as to allow the valve to open more easily. The valve-stem b is passed through a perforation in the arm f'' of the aforesaid bell-crank lever, so that the arm f'' shall be interposed between the two springs, the upper stiffer spring b' and the weaker lower spring b''; and the other arm f' is arranged so as to stand in an approximately vertical position, whereby it is adapted to contact with the tappet T secured to the tappet-rod P when the latter is removed by the valve-gear toward the left of that position shown in Figs. 1 and 9, so as to relieve the stiffness of the action of the springs b' and b''. This variation in the stiffness of the valve by the action of the springs is due to eliminating, for the time being, the compression of the stiffer spring b' and allowing the lighter spring b'' alone to keep the valve seated, after the manner as explained previously in connection with the operation of the air intake valve v'', whereby the atmospheric pressure of the air contained in the combustion chamber B resulting from the scavengering of the products of combustion therefrom by the suction of the piston a' may be varied according to the variation in tension of the springs b' and b'' of the valve 16 in accordance with the action of the tappet-bar P. It is necessary however, that sufficient tension should at all times be given to the valve 16 irrespective of the required throttling effect for the motor to maintain the air pressure in the combustion chamber B prior to the transfer of the fuel from its crank chamber to an extent considerably below that of the atmosphere.

When the engine is in operation so that the slide-valve D′ has considerable lap, that is say, when the speed of the crank-shaft is reduced below the normal working speed, the action of the governor will be to increase the stroke of the valve D′ by shifting the eccentric on the crank-shaft farther from the center upon which it rotates, and the tappet T will by contact with the arm f' relieve the spring compression from the valve 16 so as to allow this valve to admit the incoming air under a lesser pressure so that the air taken into the cylinder B will be at a higher pressure, that is, more clearly approaching atmospheric pressure, than when more pressure is required to operate the valve. The effect of this is to fill the cylinder B with a volume of air more nearly at atmospheric pressure than when the valve D′ is making a shorter stroke.

It will be observed then that the effect of the governor is not only to regulate the quantity of vapor used in operating the expansive portion of the motor, which quantity, after being rejected from the cylinder A passes out of the exhaust, after which it is further employed as the fuel for operating the explosive portion, but the quantity of air which is finally mixed with the fuel and taken into the cylinder and compressed by the inward compression stroke of the piston B′ is also controlled by the governor, and though the motor may be working on variable loads, the relative proportion of hydrocarbon to air in the explosive mixture may be maintained on all loads, but the quantity of explosive mixture used in operating the explosive portion is varied. Therefore the governor controls both the expansive and explosive portions of the motor in practically the same manner. That is to say, the mean effective pressure of both the expansive and the explosive portions of the motor is varied by the lap and lead of the slide-valve D′, without deteriorating the calorific value of the explosive combination by changing the proportion of the ingredients of the explosive portion, which would be the effect if the quantity of fuel alone was varied. It will also be noticed that the time of ignition is varied by the action of the governor as well, and the adjustment of the tappet t' (see Fig. 2) by its set screw, and the tappet-rod P must be such as to give a later ignition on light loads and an earlier ignition on heavy loads, in order to maintain a constant speed and at the same time operate the motor economically. To ascertain the manner in which the different valves should be properly adjusted so as to produce a proper fuel consumption for the motor, commensurate with the work that the engine is performing, the different adjustments for the springs on the intake valves, the vapor exhaust valves and the throttle-valve M, must be manipulated by trial until the best results are obtained, in a manner which will readily suggest itself to anyone who is familiar with the operating of gas and steam engines.

The cooling-jacket I adapted to surround the cylinder walls, has communication with the head-jacket I′, which is disposed about the cylinder-head, as shown in Fig. 1 in section, by means of a passage-way 18 formed in the castings. Within the head-jacket I′ is a float O adapted to control the amount of liquid fed to the jackets I and I′ by way of the cock K and feed-pump L. A port 9 formed in the walls of the vapor chest D, shown in Figs. 3, 4 and 7, establishes communication between the jacket I′ of the cylinder-head and the section a^4 of the vapor-jacket A^2 surrounding the cylinder A. The vapor-space 4 of the vapor-chest D has communication with the section a of the vapor-jacket A through a port 20. Each of the ports 19 and 20 has a vertical and a horizontal limb. The communicating passages which I have just described are shown in section in Figs. 3 and 7 and in plan in Fig. 4. The port 20 has a throttle-valve M (see Fig. 3) for controlling the supply of vapor to the vapor-space 4 of the vapor-chest D.

The crank-box N N′ is divided into two sections by a partition N^2. The partition N^2 has means at the crank-shaft for insuring a gas-tight connection between the crank-box chambers N N'^2 and N′ N^2, as shown in Fig. 1. The cranks C′ and C^2 rotating in the crank-box N N′ are adapted to take up oil which is located in the bottom of the crank-box, on the splash principle, in the usual manner for lubricating the crank-pins of small engines. The lubrication is also carried up into the pistons in this way and the lubrication thus afforded has been proven to be all that is necessary for both pistons and cross-heads for small-sized engines of the double-cylinder, single-acting plunger type in use at the present time.

To start the motor running, assuming that the space in the cylinder B above the piston B′ is filled with atmospheric air, the valve h of the three-way cock H must be turned into a position as to establish communication with the tempering flues 11 for the burner H″; this will bring the port H′ farther to the left than when in the position shown in Fig. 1. The liquid fuel for operating the engine is introduced through an inlet 21 provided with a plug. The fuel I prefer to use for this purpose is commercial naphtha having a specific gravity of about .7696, containing about 72% of carbon, 18% of hydrogen and 10% of oxygen. This is commonly known as stove gasolene. The naphtha burner is turned on and ignited, and after a sufficient amount of heat has been imparted to the naphtha in the jacket I, through the tempering flues 11, the naphtha will have become vaporized so that when it has a pressure of about 80 or 90 lbs. per square inch, as indicated by a pressure gage connected up to the vapor-chest D but not shown in the drawings, sufficient pressure will be found in the vapor to start the engine up expansively upon manipulating the three-way cock E so as to cause the vapor to act on the piston a, or on the piston B′ through the pipe F, according to which one of the cranks C′ or C^2 is off of the line of dead center. In order to eliminate the volume of the pipe F which would create excessive clearance for the cylinder B, a check-valve k, shown in Fig. 8, is introduced in the pipe F at a point where it enters the cylinder so as to admit of the increase of the vapor from the pipe F into the cylinder. After the motor has been turned over sufficiently by the expansive property of the vapor, the naphtha burner H″ may be turned off and also the three-way cock E, whereupon the throttle-valve M is turned on so as to admit vapor into the vapor-space 4 of the vapor-chest D, which will enable the engine to be operated by the small expansive cylinder A having its vapor admitted and cut off by the travel of the piston-valve D′ according to the speed of the crank-shaft C, as in an ordinary single-acting steam engine with a shaft governor. As the small piston a is moving downward the piston valve D′ will be moving to the left in Fig. 1, so as to admit vapor from the vapor space 4 via the port 3 to the neck d of the valve D′, and after the vapor is cut off by a reverse movement of the piston-valve D′, and the port 5 and exhaust-port 6′ have been opened so as to register with the neck d of the valve D′, the exhaust vapor will escape via the neck d of the valve D′ through port 5 into exhaust vapor space 6, and the exhaust vapor check-valve V through pipe-connections and the exhaust vapor hand-controlled valve V″ and pipe connections into the mixer V‴, and after being mixed with the atmospheric air taken in through the air intake valve, as indicated by the arrow in Fig. 2, and admitted by the hand-controlled air intake valve V^3 into the mixer V‴, the exhaust vapor, together with the atmospheric air, will be carried down through the pipe U and the check-valve V^4 into the crank-box chamber N N^2 so as to fill the entire space on the crank-side of the piston B′ and crank-box chamber N N^2 at whatever pressure the air intake puppet valve v'' will admit of, according to the tension of its springs and variations of the same by the action of the tappet t and the lever f in the stroke of the tappet-rod P, which in any event must be less than atmospheric pressure.

At the time the exhaust is just commencing to take place the small cylinder A, the piston a will be at the bottom of its outward stroke, and the piston B′ will be at the top or at the end of its inward stroke, by which time its upward displacement within the cylinder B shall have reduced the pressure in the crank-box chamber N N^2 sufficiently to take in a quantity of air through the intake puppet valve v'' from the surrounding atmosphere into the crank-box chamber N N^2 together with the exhaust vapor from the expansive portion, as already explained; and as the piston B′ is descending it will compress the mixture which was drawn into the crank-box chamber N N^2. The mixture of vapor and air contained within the crank-box chamber N N^2 at this time is incomplete, the quantity of air contained in the mixture being less by the amount of air by volume which the piston B′ displaces during its stroke than the quantity of air necessary for the best proportions of air and vapor, for an explosive mixture thereby obviating to a great extent the liability of back firing from the combustion chamber B into the crank-box chamber N N^2. The mixture contained in the crank-box chamber N N^2 however, when insufficiently mixed as stated with atmospheric air, is mixed with sufficient of the latter to render the same slowly combustible but unexplosive. The remaining quantity of air requisite to form the explosive mixture, is contained in that space within the cylinder B above the piston B′, which has been left over by the scavengering operation and is sufficiently below atmospheric pressure when the piston B′ is at the limit of its outward or working stroke to admit of the charge from the crank-box chamber N N^2 without having the total pressure in the combustion chamber B after the mixture therein is complete, greater than that of the atmosphere. In fact, as will be hereinafter explained, the pressure of the completed mixture within the combustion chamber B should be less than that of the atmosphere by the amount which the piston B′ displaces when the same is moving upwardly and the port 9 has moved to a position to overrun the port 8 after which time compression of the mixture in the combustion chamber B may commence. Conversely upon the downward movement of the piston B′ the incomplete mixture withheld in the crank-box chamber N N^2 should be sufficiently lower in pressure than that of the atmosphere to effect a balance in the pressure of the combustion chamber B after the transfer of the fuel from the former which will bring the pressure in the chamber B to the required degree. At the time when the piston B′ is descending the small piston a is forcing the exhaust all the while into the exhaust space 6 and thence through the check-valve V, through the mixing devices before mentioned and pipe U and check-valve V^4 into the crank-box chamber N N^2, and by the time the piston B′ has arrived at the position shown in Fig. 1, or at the end of its stroke, the port 6″ will register with the port 6‴, allowing the incomplete mixture which has been partly formed in the crank-box chamber N N^2 to escape by its own pressure resulting from the compression given to it by the piston B′, into the upper part of the cylinder B, through the connecting-pipe v' and back-pressure check-valve v, and perforated plate j. The effect of the passage of the mixture through the small perforations 14 in the plate J is to induce a more thorough mixing of the incoming charge with the air contained in the cylinder B, which together with the incoming charge, completes the explosive mixture prior to compression and ignition.

When the piston B′ has reached the upper limit of its inward or compression stroke, indicated by a dotted line extending across the cylinder B, (Fig. 1), the explosive mixture will be ignited by the electrical ignition plug O′ actuated by the tappet t' secured to the tappet-rod P, as aforesaid; and the piston B′ will make its first outward working stroke by the expansion of the combustible gases contained in the cylinder B. When the piston B′ has almost completed its outward working-stroke so that its port 9 will register with the exhaust-port 8′, the gases resulting from combustion will exhaust through the port 9, exhaust-port 8′, exhaust drum 9′, exhaust outlet 9″ (shown in Figs. 5 and 9) into the atmosphere. In the meanwhile the piston a' has been making its inward stroke and creating a partial vacuum in the cylinder A′. Upon a further outward movement of the piston B′ so that the piston-port 9 will register with the scavenger port 10, and the trunked extension or piston a' is moving farther in its inward stroke, and when the scavengering piston-port 8″ will also register with the port 10, atmospheric air will be drawn into the exhausting scavengering cylinder A′, through the valve h of the three-way cock H and through the air-pipe 17, check-valve 16, air passages 15, air space J′, perforations 14, piston-port 9, scavengering port 10, scavengering check-valve 10′, (shown in Figs. 6 and 9), and scavengering-piston-port 8″, thereby creating an atmospheric shower in the cylinder B of a sufficient quantity of air to displace the residual of the exhaust contained within the cylinder B and supply that volume lacking in the scavengering cylinder A′, by transferring the residual of the exhaust from the cylinder B into the scavengering cylinder A′. When the piston B′ has moved downwardly in its working stroke so that the piston port 9 registers with the port 8′, the pressure of the products of combustion in the cylinder B will, after they have made their escape by means of the exhaust drum 9′ to the atmosphere, be at atmospheric pressure, but when the piston has moved farther in the same direction so that the port 9 registers with the port 10, the exhaust port 8′ will have been cut off and the pressure contained within the cylinder B will now be slightly less than atmospheric pressure. At this instant, however, the scavengering piston a' pumps the products of combustion from the cylinder B into the cylinder A′, and draws after it the charge of scavengering air through the intake valve 16 as aforesaid, whereupon the atmospheric pressure of the cylinder B will have been considerably reduced below that of atmospheric pressure depending however on the degree of vacuum in the cylinder A′, and the resistance of the check-valve 16. In practice I have made the displacement of the piston a' somewhat in excess of that of the piston B′, so as to allow for varying displacements of air drawn into the cylinder B by the varying tension of the scavengering intake check-valve 16. The result attained by this means of scavengering the cylinder B of the residual of the exhaust and carrying it into the exhaust or scavengering cylinder A′ is an effectual clearing out of the smoke and products of the previous combustion left after the exhaust has taken place, leaving the cylinder B with a clean supply of atmospheric air with which to mix its new incoming charge of air and vapor and at the same time facilities are afforded by the piston a' for varying the quantity of residual air contained within the cylinder B after scavengering whereby the total mixture of air and mixed fuel to the crank case and entering the cylinder B prior to compression may be varied, admitting of variations in the compression of the mixture prior to ignition, which when desired may be of high value when employing a mixture containing less air and more fuel and by virtue of the corresponding temperature, due to the excessive compression it may be ignited as readily as a mixture containing a greater quantity of air at a lower compression.

I consider these features of my invention of considerable importance and of considerable advantage in efficiency in explosive engines and both of these features I consider of a distinct advantage in internal combustion motors.

Upon the downward movement of the piston a', the scavengered gases in the cylinder A′ will be forced on to the top of the piston a' through the check-valve 2, and upon the upward movement of the piston a', the scavengered gases in the scavengering cylinder A′ will be forced out through the check-valve 2′ (see Figs. 5 and 9) into the exhaust outlet 9″ and into the atmosphere, thus providing for the cylinder B a second or residual exhaust.

It will be noticed by studying the movement of the piston B′ and the piston a' that after the explosive mixture has been taken into the cylinder B on the top of the piston B′, and the piston B′ is moving upward and about to make its inward or compression stroke that some of the explosive mixture would be pushed out through the piston-port 9 and scavenger-port 10, piston scavengering-port 8″ and into the exhaust or scavengering cylinder A′. This is prevented by scavengering port check-valve 10′ interrupting the continuity of the port 10, which valve is shown in Figs. 6 and 9. The office of this check-valve is to prevent the escape of the explosive mixture from the cylinder B into the scavengering cylinder A′ when the quantity of explosive mixture in the cylinder B, is above its intake pressure, when slightly compressed by the piston B′ when making that portion of its inward stroke, to bring the piston-port 9 into register with the scavengering port 10. The seating of the check-valve 10′ therefore depends upon the degree of compression contained in the scavengering cylinder A′ as compared with the compression of the explosive mixture contained in the cylinder B. That is to say, during the upward stroke of the piston B′ and the downward stroke of the piston a', the compression of the medium or gases contained in the scavengering cylinder A must be in excess of the pressure of the explosive mixture contained in the cylinder B, so that the check-valve 10′ will be seated by the excess of the pressure of the burnt gases contained in the scavengering cylinder A′. In order to create this excessive amount of pressure in the cylinder A′ at the time of the registration of the communicating ports from the cylinder B to the cylinder A′, as already stated, the check-valve 2 must be adjusted by the tension spring shown in the drawings, which can be done by screwing up the nut on the end of the check so as to put more or less compression upon the spring. Access to the check-valve may be had through the hand-hole covered by the plate 2 shown in Figs. 8 and 9, which, in order to make gas-tight, is arranged to open outwardly from the crank-box chamber N′ N with suitable bolts and nuts and a gasket. A similar hand-hole Q′, is arranged in the crank-box chamber N N^2 but opening inwardly. The object of reversing the manner of closing these hand-holes is to provide for a better sealing-off of the gases or atmospheric air from, on the one hand, entering the crank-box chamber N′ N^2, and on the other hand, for preventing the escape of the charge for the cylinder B under pressure contained in the crank-box chamber N N^2.

It is desirable in order to obviate undue work imposed upon the engine during the creating of the vacuum in the cylinder A′ to arrange a compensating pressure device which will remove a portion of the load on the upper side of the piston *a′* during the exhausting period of the same, and to this end I have preferred to provide for the transfer of the scavengering exhaust by compressing the contents of the cylinder A′ sufficiently to lift the check-valve 2. This, however, depends upon the pressure on the other side of the piston *a′* which I control by check-valve 10″ the adjustment of which is under the influence of the engine. To this end I have arranged to release the scavengered gases held under pressure in the cylinder A′ after the port 8″ has passed downwardly beyond port 10. This gives a little vacuum above the piston *a′* with which to force the check-valve 2 open. It must be remembered that the port 10 is controlled by a check-valve 10′ which prevents any back pressure from cylinder A′ against cylinder B and permits only of transmission of the contents of cylinder B into cylinder A′. Therefore when the piston B′ has moved to a position so that the piston port 9 registers with the port 10 on an outward or working stroke, and the piston A′ is pumping or scavengering the contents of cylinder B′, and upon further movement of the piston B′ to the end of its stroke, there would be considerable compression in the clearance space above the piston *a′* which would have to overcome the seating pressure due to gravitation of the check-valve 10″. During this period the tappet T′ of the tappet-lever T″ is operated by the engine as illustrated in Fig. 9 (in which figure the crank centers are as illustrated in Fig. 1) permitting the free escape of the gases under compression above the piston *a′* through the pipe 9^3, exhaust pipe 9^4 into the atmosphere. Upon a further inward stroke of the piston B′ and a downward stroke of the piston port 8″ will register with the port 10 and the port 9 will again register with this port. It must be remembered however, that since the pressure of the charge in the cylinder B is less than atmospheric pressure, no transfer of the gases or fuel will result from cylinder B to cylinder A′ since no pressure will be imposed upon the check-valve 10′ interrupting the passage 10, but on the contrary the piston *a′* will be making a compression stroke on the scavengered gases contained in cylinder A′ which pressure will depend upon the strength of the spring of the valve 2 which will assist in holding the check-valve 10′ closed. And after the port 8″ has passed downwardly beyond the port 10, the check-valve 10″ may be released by the tappet T′ since it is desired to create a partial vacuum above the piston *a′* in order to permit of the comparatively unresisted rush of the gases from the cylinder A′ through the check-valve 2 to the other side or head of the piston *a′* and for this reason the check valve 10″ must be closed. After it has been closed by gravitation, it will remain closed by the atmospheric pressure until the gases in cylinder A′ shall have passed the check-valve 2 and have entered the cylinder A′ on the other side or head of the piston *a′*. This will be when the piston *a′* is at the terminus of its outward stroke excepting, however, for the slight excess of pressure in the cylinder A′ due to the resistance which the spring offers to the opening of the check-valve 2. On the next upward stroke of the piston *a′*, and the next downward stroke of the piston B′, a partial vacuum will be formed in the cylinder A′ as aforesaid and compression and expulsion of the gases on the opposite side of the piston *a′* will result; and in order to relieve the piston *a′* of undue work, in expelling the scavengering gases through the check valve 10″ to the atmosphere as aforesaid the tappet T′ will again open the valve 10″ and the same will remain open until the piston *a′* again returns and passes the port 10. The amount of back pressure imposed upon the piston *a′*, exerted principally between the head of the piston *a′* and the head of the cylinder A′, may be varied by permitting a more free escape of the scavengered gases through the check-valve 10″ by adjusting the stroke of the tappet T′ by shifting it on the tappet lever T″, that is to say the escape of the gases under compression between the head of the cylinder A′ and the piston *a′* may be controlled by varying the stroke of the valve 10″ (throttling the same to a greater or lesser extent).

The adjustments of the valve in the control of the working pressure of the combustible mixture, prior to ignition as just described, provides for a two cycle engine of the character under consideration, that is an explosive internal combustion motor, a means for preventing the escape of the fuel during the period when the engine is exhausting the escape of which has been a fault in two cycle motors hitherto and previous to my invention. This function, however, in the operation of the engine, I am enabled only to carry out when the working pressures of the combustible ingredients are below that of the atmosphere at the time when the fuel is taken into the cylinder and prior to compression of the same preliminary to the ignition thereof. This condition is usually referred to as throttling, and in combustion motors of the four cycle type, it has been the custom to throttle the mixture on light loads which during inhalation leaves the pressure of the combustible ingredients in the cylinder less than that of the surrounding atmosphere prior to compression. It would therefore appear that under continued throttling conditions, my two cycle combustion motor just described would for the same speed and power-output be excessive in size and consequently cumbersome. This, however, is not the case since the clearance space above the piston head in cylinder B, indicated by the dotted line, is quite small which enables the final compression of the mixture to be pushed to as high a degree as possible which in practice I prefer to make 120 pounds, thus increasing very materially the initial piston pressure and in consequence of the corresponding increased expansion of the gases, after ignition, the mean effective pressure upon the piston B′ may be made even as great or greater than were the inducted charge in the cylinder B taken in at atmospheric pressure or in other words were the column taken into the cylinder B at the initial stroke of the piston B′ equal to the capacity of the cylinder B at atmospheric pressure.

It is not usually possible to reach a high range in adiabatic compression since spontaneous ignition frequently occurs due to an overheated cylinder or piston, the temperature of which is difficult to maintain at a constant value. By my improved method of evaporating the liquid fuel from the exterior of the cylinder walls, a much better cooling effect may be obtained than by the heating of water to the boiling point as has been customary in jacketed motors or those to which my invention relates. Furthermore in consequence of the facilities to vary the mixture for the cylinder B by the amount of air delivered to it by the scavengering piston *a′* and the air taken in through the crank case by the valve V″, I am enabled to reach a higher degree of compression in the cylinder B without preignition resulting than in internal combustion engines in vogue, and hitherto and previous to my invention, thus by providing a compression of 120 pounds per square inch, it will be necessary to adjust the tension on the spring 2, and the check valve 2′, and the intake air valve V″, and the tension spring *b′*, so as to admit less atmospheric air to the cylinder B by the scavengering piston *a′*. The regulation and adjustment of the air intake V″ will proportion the quality of the mixture admitted to the crank case N^2 and N via the valve V^4 prior to a further increase of air preceding compression. Again by the evaporation of a volatile liquid, a greater transfer of heat units per second may be effected than by radiation at a corresponding temperature; thus the control of the cylinder temperature may be more closely guarded than by the methods of cooling hitherto and previous to my invention of which I am aware, thereby enabling me to compress the combustible charge in the cylinder B, prior to ignition, to a higher degree than by the usual water-cooled type of internal combustion motor; thus maintaining a large power-output for a given fuel consumption and crank shaft speed of the motor than would otherwise be possible. The check valve 10″ is operated by a tappet T′ which is operated in turn by a connecting-lever T″, and pump piston-rod L′, as more clearly illustrated in Figs. 5 and 9. The check-valve 10″ is connected up, as shown in Fig. 9, with the outlet 9‴, a small portion of which is shown in section at the top of the scavengering cylinder A′ in Fig. 1, and which is also shown in the sectional view of the valve 10″ in Fig. 9 in the interior of its chamber, in a manner so that the exit of the gases contained above the piston *a′* will be under the check into the dome of the valve, thence by an outlet-pipe (shown broken away in Fig. 9 for convenience of illustration) into the outlet of the exhaust valve 2′. The stroke given to the lever T″ by the pump piston-rod L′ is such as to synchronize with the downward movement of the piston *a′*, and the adjustment of the tappet T′ on the connecting-lever T″ must be in a manner which will give the lifting lever of the check-valve 10″ that amount of stroke which will lift the valve off of its seat, equal to the travel of the piston *a′* downward from the position which it occupies as shown in Fig. 1, until the port 8″ in the piston shall have just passed and closed the scavengering port 10, after which time the tappet T′ will no longer contact with the lifting-lever of the check-valve 10″, whereupon the check-valve 10″ will close by gravity and will remain closed until a sufficient fall in the pressure of the gases which have been transferred from the cylinder A′ through the check-valve 2′ to the top of the piston *a′* has taken place.

It will be observed in Fig. 1, that the clearance between the top part of the piston *a′* and the adjacent end of the cylinder A is quite small, and that upon a small amount of displacement of the piston *a′* in a downward direction, a great reduction in the pressure of the gases contained within this space will result. In consequence, the gases under pressure on the underneath side of the piston *a′* and in the cylinder A′ will now operate the check-valve 2 with comparatively little resistance, and the displacement of the volume of gases contained in the cylinder A′ will be effective, notwithstanding the increased tension of the spring seating of the check-valve 2; and upon the upward movement of the scavengering piston a', the gases contained in the clearance space before mentioned or that space on top of the piston a', will be ejected through the check-valve, 10'' and the outlet of the exhaust valve 2' into the atmosphere. By this arrangement, I am enabled to keep the scavengering port check-valve 10'' seated by setting up a counteracting pressure in the cylinder A' through the instrumentality of the check-valve 10'' and its connecting-gear, for a small part of the stroke of the piston a', and then suddenly releasing this pressure during the remainder of its stroke. To adjust the time of the release of this excessive pressure in the scavengering cylinder A', I have employed an arrangement for the tappet T' on the lever T''; so that the check-valve 10'' may be opened for a longer or shorter period of time during the stroke of the scavengering piston a'. As the piston B' is moving farther in its compression stroke so as to bring its port 9 into register with exhaust port 8', there would be a further tendency of the piston B' to force the explosive mixture out of the exhaust-port 8' and into the atmosphere, but to prevent this, I have introduced the exhaust check valve 2', which is adjusted for a back-pressure equal to the maximum back-pressure developed by the compression of the explosive mixture when the piston is displacing that amount of volume between the position of the port 9' in the piston shown in Fig. 1, and that position which the port 9' occupies when registering with the exhaust port 8'. That is to say, during this fraction of its compression stroke I accomplish this by weighting the valve 2' to the maximum amount of back pressure, and maintaining the adjustment at that weight, the valve closing by gravity. It will be further noticed by inspecting Fig. 1, that the joint capacity of the scavengering cylinder A' and crank box chamber N' N^2 will be less than that of the crank-box chamber N N^2, though the diameter of the scavengering piston a' is greater than that of the piston B' as hereinafter stated. The area of the upper side of the scavengering piston A, or that side of the said piston used for forcing out the residual of the products of combustion into the atmosphere should be equal to the area of the piston B', and the suction created in the cylinder A' and crank-box chamber N' N^2 by the action of the scavengering piston a' should be greater than the compression in the space below the underneath side of the piston B' in the crank-box chamber N N^2. In other words, the negative pressure of the crank-box chamber N' N^2 should be greater at its maximum than the positive pressure in the crank-box chamber N N^2 at its maximum.

When it is desired to fill the cylinder B with its charge having a pressure balancing that of the atmosphere or below that of the atmosphere prior to compression, the change of the explosive mixture being made up of air which is the residual of the atmospheric shower or scavengering charge as well as the air and vapor taken into the crank-box chamber N N^2 at the intake, and afterward fed by compression by the downward stroke of the piston B' into the cylinder B from the crank-box chamber N N^2, the volume contained in the cylinder B and the volume taken into the cylinder B from the crank-box chamber N N^2 would both be below atmospheric pressure. This diminution in the pressure of the respective volumes in the cylinder B and the crank-box chamber N N^2 is due to the resistance of the scavengering check-valve 16 and the intake valve v'' to the incoming columns being greater than that necessary to balance atmospheric pressure. In adjusting the motor so as to operate by an explosive mixture in the cylinder B at or about atmospheric pressure, as aforesaid, considerable tension will be required upon the check-valve 16 and the valve springs must be so adjusted that the residual of the atmospheric shower left in the cylinder B will be considerably below atmospheric pressure in order that the cylinder B will be in a condition to receive the additional incoming charge from the crank-box chamber N N^2, which, in consequence of being under pressure will be up to or above atmospheric pressure. It is therefore obvious that in order to perfectly displace the residual of the products of combustion after exhaust, by the piston a' when the pressure of the residual of the atmospheric shower in the cylinder B is less than that of the atmosphere, as aforesaid, the difference due to this contraction in the quantity of the air contained in the cylinder B must be made up by the displacement of the piston a' in the cylinder A'; and in making up this difference by the displacement of the piston a' in the cylinder A', the amount of compression of the gases in the crank-box chamber N N^2 by the downward movement of the piston B' must be considered. It is therefore obvious that the exhaustion of the scavengering cylinder A' must have a greater negative value than the compression in the crank-box chamber N N^2 by the piston B'. I have therefore preferred to not only increase the area of the scavengering piston a' so as to provide for a surplus quantity of air employed in the scavengering process, but also have contracted the capacity of the crank-box chamber N N^2 so that the pressure due to the exhaustion shall be high. The object of having a comparatively low pressure in the cylinder B when the engine is working at its normal load and before compression, is to prevent the escape of the exhausted gases when there is still a sufficient quantity of heat contained in the gases to perform useful work.

Many of the explosive engines employed at the present time utilize the expansive property of their combustible mixture by adjusting their intake valves so as to have the volume of explosive mixture in the cylinder considerably below atmospheric pressure when the piston is at the limit of its outward stroke prior to compression, so that the compression may be carried up to almost as great a pressure as the initial piston pressure when ignition takes place, and have considerable room left in the cylinder while impelling the piston forward in its working stroke for a long expansion of the gases when performing the mechanical work of the engine. It is this thermodynamic consideration which I have reference to in describing the relative capacities of the cylinder A′ and crank-box chamber N′ N^2 and the underneath side of the piston B′ and crank-box chamber N N^2 commensurate with obtaining a complete scavengering effect of the cylinder B, together with a good margin for expansion of the combustible mixture in the cylinder B after ignition.

By the manner of adjustment whereby I am enabled to vary automatically the volume of air and explosive mixture taken into the cylinder B, I am enabled to operate my motor on fluctuating loads and mean loads with a high degree of economy from a thermodynamic standpoint; and on overloads when the motor is operating beyond its normal rated capacity the means for varying the supply of fuel taken into the cylinder B is such that the volume of gas contained within the cylinder B may be considerably in excess of that of the atmosphere before compression. In fact, it may be all of that in excess of what the piston B′ displaces when it is making its downward stroke with all of the tension taken off of the intake valve, as before explained, so as to admit of the air being taken into the crank-box chamber N N^2 at very nearly atmospheric pressure prior to the downward displacement of the piston B′. During the operation of the engine and at the time when the valve D′ shall have moved into a position for release so as to open the exhaust-port, and the piston a' is at the end of its inward stroke, the piston B′ will be at its upper or compression stroke, at which time the suction created in the crank-box chamber N N^2 by the upward displacement of the piston B′ will be such as to first draw in the exhausted gases from the exhaust-space 6 of the expansive section through the vapor exhaust check-valve V prior to the intake of air from the atmosphere through the air intake check-valve v'' by reason of the tension of the springs s and s' seating the said valve, the air having to work against the resistance of the said springs. The effect will be to effectually exhaust the vapor from the exhaust-space 6 after the manner of a vacuum pump so as to leave the exhaust pressure in the vapor cylinder A at that time below atmospheric pressure, after which the exhaust vapor check-valve will be closed down against its exhaust by the increased pressure of the atmosphere and the inrush of air through the air intake check-valve v'' so that when the piston a is returning and making its upward stroke, the exhaust is merely that against atmospheric pressure plus the weight of the small check-valve V, and the slight compression due to the downward movement of the piston B when at about three-quarters of its stroke. By this time, the piston-valve D′ will have closed the exhaust port so as to cut off the exhaust and prevent any further back-pressure from the compression due to the downward movement of the piston B′. Of course this depends upon the lap and lead of the slide-valve D′ in its travel, which is varied in accordance with the speed of the shaft-governor during the variations in the speed of the motor.

When employing the commercial naphtha for operating my thermodynamic motor, the quantity of vapor necessary for the fuel for the explosive portion may be varied at will by varying the pressure contained in the jacket I. In the event of the naphtha vapor being in excess of that required for the explosive cylinder to constitute the best proportion for the explosive mixture, the initial pressure may be increased in the jacket I, and the valve D′ adjusted so as to cut off earlier in its stroke, or the vapor may be throttled by the throttle-valve M; and in the event of a deficiency occurring in the quantity of the naphtha vapor rejected by the cylinder A for proper combustion in the cylinder B, the reverse manner of adjustment may be resorted to.

In order to reduce the pressure of the vapor in the jacket I, I reduce the temperature of the naphtha either by pumping cold air directly from the atmosphere into the cylinder B by the exhausting action of the scavengering piston a' in the scavengering cylinder A′, or indirectly through the tempering flues 11 or by both. I accomplish this by turning the valve h of the cock H into a position so as to turn off the supply of air which, as previously stated, was drawn through the cock H, supply-pipe 17 and check-valve 16; and by turning the valve h into a position so that the port h' will register with the smoke-flue 13, communication of the pipe 17 with the smoke-flue 13 will be established by the cock H, and the supply of air to the cylinder B will be taken in through the tempering flues 11, smoke-flue

13, air supply pipe 17 and check-valve 16. When the motor is in operation the cold air which is continuously drawn in through the tempering flues will take up the excessive heat of the naphtha contained in the jacket I so as to reduce the working pressure of the vapor. Of course this heat is also taken into the interior of the cylinder and is added to the explosive mixture, and in case of the heat being still excessive so as to produce too great a pressure, the cock H can be manipulated so as to allow some cold air to enter through the check-valve 16 as well as heated air through the tempering flues 11. The amount of air taken in through the intake scavengering check-valve 16 as already stated, is varied by the variations in the compression of its spiral compression springs.

In large engines of this class, when it is not practical to lubricate the interior of the cylinder in the manner before stated, I employ independent lubricating devices in the ordinary way for lubricating the cylinders of gas engines. In order to permit of the removal of the liquid in the jacket I, I employ a drain-cock R having a passage-way (shown in dotted lines in Fig. 1) in the casting of the cylinder B at the lower end. A similar cock R′ (shown in Fig. 1) is employed for the vapor jacket A.

In making use of the term "explosive engine" throughout this specification, I mean those engines in which the fuel is burned behind the piston within the working cylinder, and therefore the term has reference to a variety of engines of the slow combustion type in which the fuel is fed in more or less gradually and consumed behind the working piston; and, as I do not wish to confine my invention to either rapid or slow combustion engines, I wish to make myself explicit in this respect, that in using the term "explosive engine" I mean those engines known in the trade as the internal combustion type as well as those commonly known as the explosive type, as the principle of my invention may be employed with either the slow or rapid combustion types of engine without departing in the least from its spirit.

Although I have described my invention in thermodynamic motors using an expansive portion of about 11.12 per cent. of the cylinder capacity of the explosive portion, I do not desire to limit myself to these proportions in reducing my invention to practice. I have considered, however, that a part of the forty per cent. of heat wasted ordinarily in explosive engines could be best used in a simple manner by carrying out proportions of about those specified. Obviously by using a greater quantity of the volatile liquid than that which could be used as fuel for the explosive portion, a greater portion of the forty per cent. could be utilized, and the expansive portion could therefore be made larger, but an additional cooling agent would have to be employed to reduce the temperature of a greater part of the vapor after the same has been rejected by the expansive portion. As the quantity of naphtha contained in the expansive vapor would have to be reduced so as to meet the requirements demanded for the best chemical conditions for operating the explosive portion, this would mean that the vapor would have to be put through a pump and condenser and brought back to a liquid state, and returned by the pump to the jacket I to be used over again, which would introduce objectionable features in the operation of the engine from a commercial stand-point; and in consequence I have confined myself in the description to what I considered the most simple method of operating a thermodynamic motor on the expansive and explosive principle, by employing only one liquid for the fuel, the power medium and the refrigerator for the explosive portion.

I have throughout this specification occasionally referred to my improved motor as being divided into two portions, terming one of these the explosive portion and the other the expansive portion. I mean to infer by this that a portion of the motor is operated directly by the explosive power of the combustible ingredients, and another portion of the motor is operated indirectly by the heat thereof and through the expansion of a medium which takes up the heat through the heated parts of the motor with which the same is in contact during the conflagration or combustion of the fuel. I therefore desire to interpret the explosive portion of the engine as that portion lying to the right of the dotted line 9 as indicated in Fig. 1, and the expansive portion as that portion lying to the left of the said dotted line.

I will hereinafter occasionally refer to the expansive portion thus interpreted as that of a thermodynamic transformer in which the heat is transformed into work by the indirect process, since the significance is similar in this sense to the application of heat in the vaporization of water in order to operate a steam engine, and to the explosive portion thus interpreted as a thermodynamic transformer wherein the heat is transformed into mechanical work by direct transformation; or I may, in this connection, in further pursuit of defining the function of these two portions and in order to differentiate them when referring to the motor as a whole, consider the same as a thermodynamic motor possessing a dual function to wit:—one in which heat is transformed into work by both the primary and secondary thermodynamic process. By the primary thermodynamic process I mean the direct application of heat into mechanical work as is exemplified in the explosive portion of my improved motor wherein the expansion of the gases resulting from combustion acts directly as upon the thermodynamic translating instrumentalities, that is the piston B′ and the crank and connecting rod co-acting therewith; and by the secondary thermodynamic process I mean the indirect application of heat into mechanical work as is exemplified in the expansive portion of my improved motor wherein the expansive power medium as previously referred to derives its energy in expanding behind the thermodynamic translating element, as for example the piston *a* in the driving of the connecting rod I and crank *c′* in the performance of mechanical work.

I shall occasionally refer to the transfer of heat into mechanical motion or work as that of a thermodynamic transformation, and shall refer in general to the piston and cylinder or the pistons and cylinders and their cranks and connecting rod as thermodynamic transforming elements.

I am aware that previous to my invention expansive and explosive engines have been so combined that the expansive engine was employed as a starting device for the explosive engine. I am also aware that steam engines and gas engines, so-called, have been combined so as to work upon the same crankshaft. I do not claim these features as my invention.

I do claim however, and desire to secure by Letters Patent of the United States:—

1. The combination of an explosive engine, a liquid fuel supply exposed to the heat of the cylinder of said engine, an expansion engine connected to said supply to be driven by the vapor developed from said fuel, and connections leading the exhaust of the expansion engine to the charge inlet of the explosive engine.

2. In a thermodynamic motor, a combustion and expansion chamber, a liquid fuel receptacle, a combustible liquid power medium in contact with the combustion chamber carried by the said receptacle adapted to operate the motor by the vaporization thereof through the transfer of heat from the combustion chamber, a connection between the said receptacle and the expansion chamber, means for controlling the admission and cut-off of the vapor in the expenditure of the energy thereof within the said expansion chamber in the performance of mechanical work and for controlling the exhaust thereof, together with means for conflagrating a quantity of the spent vapor within the combustion chamber in the further performance of mechanical work.

3. In a heat engine, the combination of an explosion cylinder having a fuel supply receptacle in contact therewith, the fuel therefor adapted to be heated by a surplus of the cylinder heat of the explosion cylinder, an expansion cylinder, pistons within each of the cylinders, the piston within the expansion cylinder being operated by the fuel heated by the surplus heat of the explosion cylinder, a connection between the two cylinders for permitting the transfer of the said heated fuel, and a valve and valve-gear for controlling the exhaust of the expansion cylinder into the explosion cylinder.

4. In a heat engine, the combination of an explosive engine and a fuel supply receptacle therefor, the same being adapted to contain a quantity of fuel and subject the same to the heat of the cylinder, and an expansion cylinder adapted to receive said heated fuel and wherein the same is adapted to expand in the further operation of the motor, the explosive cylinder having a greater piston area than the expansion cylinder, a connection between the exhaust of the expansion cylinder and the charge inlet of the explosive cylinder, for permitting the escape of the exhaust of the expansion chamber to the charge inlet of the explosive cylinder.

5. In a heat engine, the combination of an explosive engine having a fuel supply receptacle carried by its cylinder and adapted to subject the same to the action of the heat thereof, and an expansion cylinder co-acting with the explosive engine and operated by the expansion of the heated fuel, a connection between the exhaust of the expansion cylinder and the charge inlet of the explosive cylinder, a fuel mixing device interposed therein having controlling valves operated by the engine for mixing and controlling the fuel supply of the explosive engine.

6. In an explosive engine, the combination of a vapor generator heated by a surplus of the cylinder heat of the said engine, of an auxiliary expansive heat engine deriving its energy from the sensible heat of the vapor of the said vapor generator, and of an independent heating device for the vapor generator consisting of a burner and heating flues said heating flues having a bypass regulator and suitable pipe connection therefor for controlling the heating effect of the flues.

7. In an explosive engine having a vapor generator heated by a surplus of the cylinder heat of the explosive engine, and an auxiliary expansive heat engine deriving its energy from the sensible heat of the vapor of the said vapor generator, the combination of an independent heater for the said vapor generator having hot-air flues therefor, and of a valve and cold air pipe for the

vapor generator and said flues said valve being adapted to supply cold air to the hot air flues while in one position, and regulating the draft for said heater through the said hot air flues while in another position.

8. A thermodynamic motor having a combustion chamber and a piston within the said chamber, a vapor generator for the combustion chamber, a second chamber having a piston said second chamber communicating with the vapor generator, and a liquid within the generator vaporized by the transmission of heat through the walls of the combustion chamber, and devices for liberating and conveying the heated vapor to the second chamber and for transforming the spent vapor from the said chamber, and for communicating the same to the charge inlet of the combustion chamber.

9. An explosive engine having a vapor generator deriving its heat from the cylinder of the explosive engine by transmission through the cylinder walls, and an auxiliary expansive engine deriving its energy from the sensible heat of the vapor of the said vapor generator, and an auxiliary heat generator together with a tempering device for regulating the heat of the vapor contained in the said generator.

10. In an explosive engine, the combination with the cooling-jacket, of a temperature regulator connected therewith to moderate the refrigerating effect of the heat absorbing medium contained in the cooling-jacket by the operation of the engine, of additional means for moderating the refrigerating effect of the heat absorbing medium contained in the cooling-jacket independent of the operation of the engine, and of a controller for the temperature regulator.

11. In an internal combustion engine wherein the products of combustion exhaust through a port uncovered by the piston of the said engine when making its forward stroke, and wherein the fuel for operating the said engine is taken into the cylinder after the exhaust has taken place, the combination with the exhaust port of a valve controlled by the operation of the engine adapted to prevent the escape of the fuel at the initial of the return stroke of the piston.

12. In an internal combustion engine wherein the products of combustion are permitted to escape from the cylinder of the said engine toward the terminus of the outward stroke of the piston, and wherein the residual of the products of combustion is cleared from the cylinder by a scavengering charge admitted to the cylinder after the piston has moved farther in its stroke, and wherein, upon a further movement of the piston, fuel for the engine is taken into the cylinder, the combination with the entrance passages to the cylinder, of means governed by the engine adapted to withhold the working charge of the said engine at a pressure below that of the atmosphere, and to prevent the escape of the same from the cylinder of the said engine at the initial of the compression stroke of the piston.

13. In an internal combustion engine, wherein the scavengering charge is taken into the cylinder of the engine for eliminating the products of combustion in the cylinder, the combination with the intake valve, of an automatic pressure controlling device governed by the operation of the engine, adapted to control the pressure of the residual of the scavengering charge according to variations in the speed of the engine, said residual of the scavengering charge co-acting with the fuel charge in forming the combustible mixture for the engine.

14. In an internal combustion engine wherein the scavengering charge is taken into the cylinder of the engine for eliminating the products of combustion in the cylinder, the combination with the intake valve of an automatic pressure controlling device governed by the operation of the engine adapted to control the pressure of the residual of the scavengering charge and withhold the same at a pressure below that of the atmosphere, and in accordance with the variations in the speed of the engine, said residual of the scavengering charge forming a portion of the explosive mixture for the engine.

15. In an internal combustion engine, wherein the working charge and the products of combustion are controlled by the working piston in the uncovering of cylinder parts therefor, a pneumatic scavengering device co-acting with the operating parts of the said engine for clearing the cylinder of the said engine of the products of combustion and means co-acting with the exhaust whereby the same is adapted to clear out the products of combustion of the exhaust after the release thereof has taken place and prior to the admission of the explosive mixture for operating the engine, and of controlling means for withholding the same at a pressure below that of the atmosphere.

16. An internal combustion engine of the two-cycle type provided with a pneumatic scavengering device for clearing the cylinder of the said engine of the residual of the products of combustion after the exhaust has taken place, and means for admitting the explosive mixture into the cylinder after the said residual of the products of combustion has been cleared, and of controlling means for withholding the same at a pressure below that of the atmosphere.

17. An internal combustion engine provided with a pneumatic scavengering device for scavengering the cylinder so as to clear

it of the products of combustion after it has transformed its heat of chemical combustion into mechanical work, said engine having means for admitting the scavengering charge to the cylinder between the time of charging of the cylinder with the combustible mixture for operating the engine and the time of the escape of the exhaust from the cylinder of the said engine, and controlling means for withholding the same at a pressure below that of the atmosphere.

In testimony whereof I have signed my name to this specification in the presence of two subscribing witnesses.

PHILIP K. STERN.

Witnesses:
CHAS. WAHLERS,
ABRAHAM J. SPIRO.