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(54) **IMPROVEMENTS ON HOT AIR ENGINES**
(54) **PERFECTIONNEMENTS AUX MACHINES A AIR CHAUD**

To all whom it may concern:

Be it known that we James Atkins Woodbury - Joshua Merrill - George Patten - and Edward Franklin Woodbury - all of Boston - in the County of Suffolk and State of Massachusetts - one of the United States of America all Mechanical Engineers - have jointly invented certain - new and useful improvements in Air Engines - of which the following taken in connection with the accompanying drawings is a specification.

The invention relates to that class of air engines which are operated by alternately heating and cooling the same body of air over and over again, and to that particular kind of such engines in which a working cylinder and piston are used in combination with a reverser, and has for its object the production of engines capable of being operated by air at very high pressures, and also capable of heating and cooling the air with very great rapidity -

It is a well known fact that the application of about 480 degrees of temperature to atmospheric air in a confined state doubles its pressure, and it has been proved by practical experiment that the

same number of degrees of temperature ab-
plied to air compressed to a pressure
equal to two, four, or more atmospheres
doubles its pressure as in the case of common
atmospheric air.

It is also well known that a given amount
of fuel applied to heating air develops
about four times the amount of mechan-
ical force that the same amount of fuel
develops when applied to the generation
of steam from water.

After a long series of practical experi-
ments made by the inventors in working
air under high pressures - it has been found
that it takes no more units of heat to raise
air compressed to a pressure equal to two-
four or more atmospheres to a given temper-
ature than it does to raise common atmos-
pheric air to the same temperature, and
therefore it is obvious that there must
be a great gain in operating air engines
with air at very high pressures.

The invention consists in certain im-
provements in the construction and
arrangement of the parts - which will
be readily understood by reference to the
description of the Drawings hereinafter
given.

Figure 1- is a plan of an engine embodying our invention.

Figure-2- is a front elevation.

Figure-3- is a rear elevation.

Figure-4- is an end elevation.

Figure-5- is a vertical section on line 1-1- on Figs- 1- and 2-

Figure-6- is a vertical section on line 2-2- on Figs. 1 and 2-

Figure-7- is a horizontal section through one reverser and one working cylinder on line 3-3- on Fig. 5-

Figure-8- is a partial vertical section of the working cylinder on line 4-4- on Figs- 1 and 2- enlarged.

Figure-9- is a partial vertical section of the reverser cylinder and the refrigerator on line-7-7- on Fig. 1- enlarged.

Figure-10- is a horizontal section through the working cylinder on line 5-5- on Fig-5- enlarged.

Figure-11- is a partial vertical section of one side of the working cylinder on line 6-6- on Fig- 1- enlarged.

Figure-12- is a plan of the inner reverser cylinder-

Figure-13- is an elevation of said inner cylinder- with the regenerator plates attached thereto.

Figure - 14 - is a horizontal section through the reverser cylinder and regenerator plates on line 3-3- on Figure - 13-

Figure - 15 - is a detail of the governor connections to the throttle valve.

Figures 16 and 17- are respectively an inverted plan and sectional elevation of a portion of the heater for one working cylinder.

Figures - 18 and 19- are respectively an inverted plan and sectional elevation of a portion of the heater attached to one reverser cylinder.

Figures - 20 and 21- are respectively a plan and sectional elevation of a portion of the cooler.

Figure - 22- is a partial horizontal section of one of the annular heaters on line 6-6- on Fig - 6-

Figure - 23- is a side elevation of the cylinders and beams of a modified form of engine, and Fig - 24- is a sectional elevation of the same - the cutting plane being through the working cylinder on line 4-4- on Fig - 23-

In the drawings A and A' are two fire-boxes or furnaces mounted upon

the bed plate B and provided with the grate a - ash-pit C - fire-door b - and ash-pit door c - all constructed in a well known manner

The fire box casings A and A' extend to the rear of the combustion chamber sufficiently far to serve as supports for the working cylinders D and D', the rear portion being partially separated from the combustion chamber by the bridge wall E above which the products of combustion pass through the flue E' across the chamber F and thence escape into the chimney - (not shown) through the passage F'.

The working cylinders D and D' are cast open at both ends, and provided at their lower ends with broad flanges d the outer portions of which rest upon and are securely bolted to the casings A and A' - while to the inner portion of the same flange of each cylinder is firmly bolted the heaters.

The heater under the working cylinder D is composed of the circular plate head G and a series of U shaped tubes e-e- arranged as shown in Figs. 16 and 17 - so that the body of each of said tubes depends from said plate into the chamber

F and its two ends hast through the head G at different distances from its centar and the centre or axis of the cylinder D:

The lower portion of the cylinder D is made of somewhat greater diameter than the upper portion, and has fitted therein the short secondary cylinder or shield f- the lower end of which rests upon the head G while its upper end is provided with an outwardly projecting narrow flange or band f' which fits the chambered portion of the cylinder D- said shield being made of such a length that its upper end does not quite reach the shoulder g of the cylinder D- when its lower end rests on the head G to allow for unequal expansion- three or more coiled metal springs g' being inserted between said shoulder g and the upper end of said shield to insure contact between the lower end of said shield and the head G as shown-

Between the shield f and its cylinder is an annular space h the central portion of which is made eccentric to said shield as shown in Fig- 9- into which one end of each of the tubes e- e- opens- while the other end of each of said tubes opens into the chamber beneath the piston H-

the rubber portion of which is fitted loosely in the rubber portion C' of the cylinder so as to be guided thereby in its inward and downward movement while its lower portion is reduced in diameter so as not to touch the cylinder as shown in Fig. 5

The cylinder D' is constructed in all respects like D but it has bolted to its lower end the annular cast metal heater D^5 and the shield S extends into said heater nearly to the bottom of the annular space between its outer and inner walls as shown in Fig. 6.

The rubber ends of the cylinders D and D' are closed by the cylinder heads D^2 and D^3 each provided with an opening for the passage of the piston rod I and two cupped packing rings i to prevent the escape of air around said rod the upper end of which is connected by the link J to one end of the beam K or by a similar link to the opposite end of said beam which is also connected by its arm K^2 and the rod K' to the crank L upon the driving shaft L' mounted in bearings upon the standards M.M and having secured to its opposite end the crank L^2 and carrying the driving pulley L^3 as shown.

The rubber end of the piston H has

fitted to a suitable groove formed therein: a metal backing ring j firmly secured to the piston so as to move with it - A cupped leather backing may be used instead of the metal ring - if desired.

The beam K has its bearing upon the stand K" supported by the cylinders D and D' - or said stand may extend downward to and be supported by the bed-plate B.

N and N' - are the outer cylinders of the two reversers - each provided with a broad flange l at its lower end - the outer portion of which rests upon and is firmly bolted to the furnace casing A or A' in a position directly above the grate a - the lower end of which cylinder is closed by the heaters firmly bolted to the inner portions of the flange l -

The heater beneath the reverser N is composed of the circular disc or head O - and a series of U shaped tubes e' which depend therefrom into the combustion chamber and are arranged relative to each other as shown in Figs - 18 and 19 - and communicate through the head O - with two separate chambers substantially as heretofore described in connection with the heater attached to the working cylinder

D-

To the lower end of the outer reverser cylinder N is bolted the annular cast metal heater N² as shown in Fig- 6-

P is the inner cylinder of the reverser made of somewhat less diameter and placed within and concentric with the cylinder N with its lower end resting on the plate O in such a manner as to form an annular chamber between the cylinders N and P to serve as a regenerator.

The upper ends of the cylinders N and P are closed by the head Q - which is firmly bolted to the cylinder N - and rests upon a rubber packing ring m - placed in a groove in the upper end of the cylinder P to form an air tight joint - and allow for unequal expansion.

The head Q has set therein and projecting upward therefrom a series of tubes n - bent into the form of an inverted U - and arranged as shown in Figures 20 and 21 - one end of each of which communicates with the space between the cylinders N and P - and the other end with the interior of the cylinder P - above the reverser piston R - and is also provided with the central upwardly projecting tubular hub Q' through which the pis-

tion rod R' passes - and to the upper end of which is secured the upper end of the cooler casing S - the lower end of which is firmly bolted through the head Q to the cylinder N - thus forming a cooling chamber enclosing the liner n to be filled with cold water, as will be hereinafter described.

The upper end of the piston rod R' is connected by the link T to the beam U whose one side of the stand V in which said beam has its bearings - while said beam is connected upon the opposite side of said bearing by the link T' and piston rod R² to the reverser piston in the reverser cylinder which is constructed in all respects like the one heretofore described.

The pistons H and R are each cast in two parts and screwed together so as to form hollow air tight chambers therein - the lower portion of each of which is filled with fire-brick X⁶ - and the upper portion with asbestos X⁷ - as shown in Figs 5 and 6.

The beam centre U' has firmly secured to its outer end the pendent arm V provided with the pin V' - by means of which the beam U and the reverser pistons may be worked by hand to start the engine -

or by means of the hook connecting rod W and the crank L^2 said beam and histon may be worked by the power exerted by the working histon H - the hook end of the rod W engaging with the handle or pin V' - as shown in Fig - 2.

V^2 is a pendent arm hanging loosely from the beam centre V^2 just outside of the arm V, and having fitted to a socket in its lower end the rod m^4 - the lower end of which is hinged to the hook connecting rod W - and provided with a detent notch m^5 with which an inwardly projecting tooth on the lower end of the spring m^6 attached to the arm V^2 engages to hold up the hook W - when raised up to disengage it from the pin V' - a cam lever m^7 - being pivoted to said spring as a means of withdrawing said tooth from the notch when it is desired to drop the hook W onto the pin V'.

The inner reverser cylinder P - has formed upon its upper end three or more outwardly projecting lugs - o - o - as shown in Figs - 9 and 13. which rest upon shoulders formed in the upper end of the cylinder N to support said cylinder P - when the cylinder head O is removed - and is provided near its lower end with a lateral opening p through an outwardly projecting boss p'.

the outer end of which fits closely to the inner periphery of the cylinder N immediately around a corresponding opening through the pipe q projecting horizontally from the rear of the cylinder N - through which and the pipes q' and q^2 air may pass freely from the exterior of the reverser cylinder to the annular space h in the working cylinder - and thence through the pipes e - e to the space beneath the working piston H and vice versa - when the throttle valve r - is open -

The lower end of the cylinder P - is also provided with two or more outwardly projecting lugs p^2 - p^2 which co-operate with the boss p' to register the lower end of said cylinder and maintain it in its proper position within the cylinder N - shown in Fig. 12

The inner reverser cylinder P" is constructed in all respects like P - except that it extends downward nearly to the bottom of the space between the inner and outer walls of the annular heater N^2 - without touching either wall so that the air must pass around the lower end of said cylinder spread into thin films on either side thereof and exposed to great heat from the fire in the furnace - in order to

pass from one side of the reverser piston to the other.

In the annular spaces between the lower portion of the cylinder P' and the inner and outer vertical walls of the heater N^2 and between the lower portion of the shield S in the working cylinder and the inner and outer vertical walls of the heater D^5 are placed corrugated plates or rings u - of thin metal so as to divide said annular spaces into a large number of small vertical passages, as shown in Fig - 22 -

The fire-grate a is provided with a downwardly projecting leg a' in which is formed a socket to receive the end of a lever a^2 shown in dotted lines in Figure 5 by which the grate may be partially rotated about a vertical axis of motion for the purpose of removing the ashes from the fire.

A throttle valve x is placed in each of the pipes q - and mounted upon opposite ends of a rocker shaft x' extending from one pipe to the other, and having secured thereon a short lever x^2 - to the movable end of which is connected one end of the rod x^3 - the upper end of which is connected to one end of the lever x^4 hinged to the stand X' - and connected at its other

end with the vertically moving rod x^5 of the governor X in such a manner that a radial movement of the governor balls shall move both of said valves about their axes to open or close them according as the speed of the engine is diminished or increased.

The lever x^2 may be used as a hand lever for the purpose of closing or partially closing the throttle valves x in opposition to the action of the governor - for the purpose of slowing the engine.

In some cases a throttle valve actuated by a governor may be placed in a pipe or passage way connecting the top and bottom - (or space above and below the piston) of each working cylinder for the purpose of controlling the speed of the engine, and another valve or cock operated or set by hand may be placed in the said pipe in order to control or limit the sensibility of the governor's action -

By partially closing this latter valve or cock a too sudden passage of air from below to above the piston may be controlled independent of the throttle worked by the governor.

The spaces between the cylinders N and x^3

and N' and P' are filled with a series of thin sheet metal plates b^2 attached to the outer surface of the cylinder P by means of the studs c' and screws c^2 the holes in each of said plates for the passage of the studs c' being slotted as shown in Fig-13- to allow for unequal expansion.

The plates b^2 are each provided with one or more vertically arranged ribs or corrugations d' of slight projection with broad plane surfaces d^2 at either side thereof - said ribs serving the purpose of keeping said plane surfaces from coming into close contact - and thus forming a series of very thin annular or segmental passages through which the air is compelled to pass from the heater to reach the cooler - or vice versa - said plates being shown in Figs- 9- 13 and 14- the number and thickness of said plates and distance apart thereof being such as to give the best results in rapid heating and cooling of the air.

D^4 is an air pump provided with suitable valves and a plunger - (not shown) to which a vertical reciprocation is given by means of the connecting rod g^2 and the wrist pin g^3 set in the end of the beam V- said pump being arranged and a-

dahled to force air under pressure through the tube h' - check valve h^2 and tube h^3 into the working cylinders D and D' above their pistons H, and through tubes h^4 and check valves h^5 set therein, into the reverser cylinders N-N.'

F^2 is a plunger circulating pump operated by the wrist pin i' set in the opposite end of the beam V - acting through the connecting rod F^3 - and adapted to force water through the tubes j' and j^2 into the interior of the cooler casings S.S. thence through tubes k^2 and k^3 into the annular chambers l' and l^2 surrounding the upper ends of the reverser cylinders N-N' to prevent the transmission of heat to the cooler O-x-S- and thence through tubes m' and m^2 to the annular chambers n' and n^2 surrounding the working cylinders D and D' respectively near the middle of their height or at points below the lowest position to which the packing rings J-J' on the upper ends of the pistons H descend to prevent heating the upper portions of the cylinders D and D' to such an extent as to injure the packing, j, the water being finally discharged from the chambers n' and n^2 through the tubes

o' and o² into any convenient receptacle (not shown).

The piston rod R' is packed by cupped leather packing rings p² secured to the upper end of the hub Q' of the cylinder head Q- as shown-

The tubes of the tubular heaters and coolers instead of being bent to a U shape may be straight tubes with their lower ends connected by half turn junctions or an annular tube - if desired - without departing from the principles of the invention - but the U shaped tubes are preferred as being the best construction all things considered.

The operation of the invention is as follows. The cranks L and L² being set so that the crank L² leads the crank L, in regard to the effect produced when the respective pistons operated thereby - from seventy to ninety degrees - supposing the crank shaft to be revolved in the direction indicated by the arrow on Figures 2 and 3 - if a fire be built upon the grates a so as to heat the air in the heaters O e', and N²; to start the engine the operator disengages

tie hook rod W from the pin V' and - by means of the handle of said pin V' moves the beam V by hand through an arc limited by the stops t-t- and thereby moves the reversing pistons alternately up and down in their respective cylinders - the effect of which is that the pistons in the reverser cylinders displace the air contained therein by driving the air in the cold end of one of the said cylinders down through the tubes n and the regenerator space into the tubes e' and driving the air in the hot end of the other reverser cylinder through the tubes e' and the regenerator space into the tubes n - thereby greatly increasing the pressure in one reverser cylinder and in the lower end of one working cylinder - and correspondingly diminishing the pressure in the other reverser cylinder and the lower end of the other working cylinder with which it communicates - while no change in the pressure above the working pistons takes place - the effect of which is that the increase of pressure beneath one of the working pistons causes it to be moved up

ward till it reaches the extreme of its upward stroke when the reverser pistons are made to change their positions by hand thereby diminishing the pressure beneath the working piston which has just completed its upward stroke and increasing it beneath the one that has just completed its downward stroke thus creating a differential pressure beneath the two working pistons - by means of which the engine is set in motion - the pressure alternately changing from one cylinder to the other - when the hook W is allowed to engage with the pin V - and the reverser pistons will then continue to be worked by the power of the working pistons - and the air pump and the water circulating pump will be set in motion and made to perform their respective offices of forcing air into the upper ends of the working cylinders under pressure and circulating cold water around and through certain parts of the engine to keep such parts cool

As air is pumped into the engine the pressure is increased therein by compressing the air throughout all the air cham-

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bers and passages - but the air in the working cylinders above their respective pistons not being affected sensibly by the heat from the furnaces remains substantially at its normal pressure - and as the two chambers above said pistons are connected by the pipe $\frac{7}{8}$" through which the air contained in said chambers may pass freely in either direction as one piston ascends and the other descends and as the aggregate of the cubical contents of the two chambers is at all times substantially the same in whatever positions the pistons may be placed - it follows that there will be no material change in the pressure in said chambers - except such as is due to the compression of the air by pumping in more air - and this being understood it will be equally clear that the power of the engine will be determined by the difference in the pressure alternately created in the reverser cylinders by the movements of their pistons heating the air in one reverser cylinder and cooling it in the other - thereby at each

stroke of the engine increasing the pressure beneath one working piston and diminishing it beneath the other working piston.

With the cranks adjusted to give the proper lead - and the beams in the position shown in the drawings - the piston in the working cylinder D will be at the centre of its upward movement - and the piston in the working cylinder D' will be at the centre of its downward movement while the piston which works in the reverser cylinder - which is in direct communication with the lower end of the cylinder D - has not quite reached the extreme of its upward stroke - and the other reverser piston has not quite reached the extreme of its downward stroke.

The downward stroke of the reverser piston forces the hot air beneath it through the tubes $\underline{e}$ through the regenerator space among the plates $\underline{k}^2$ - which extract a large proportion of the heat from the air as it passes - and through the tubes $\underline{e}$ - which are surrounded by cold water - as before described, into the space above said piston

thereby reducing the pressure beneath the piston of the working cylinder - which has just completed its upward stroke - while at the same time the other reverser piston by its upward motion is forcing the cold air above it through the pipes n - through the regenerator - where it takes up a large amount of heat from the plates b² - through the pipes e' - where it is heated, through the lower part of the cylinder P - pipes q - q' - and q² and e where it is still further heated - and discharged into the space beneath the piston in the working cylinder to exert its power - due to the increase of pressure caused by the rise in temperature, upon said piston to move it upwards.

This operation is repeated as long as power is desired to be used - the increase of pressure and consequent development of power alternating from one working cylinder to the other - each of said working pistons being controlled by its own reverser piston - as above described - and by the throttle valve in the pipe q - and the governor connected therewith.

In Figs. 23 and 24 is illustrated a modified form of the engine - having one double acting working cylinder and two reversers the heated end of one of said reversers being connected by the pipes q q' q² to the lower end of the working cylinder - and the heated end of the other reverser being connected by the pipes q and q" - with the upper end of the working cylinder in such a manner that heated air is alternately admitted to the working cylinder upon opposite sides of its piston.

In the modification here shown an annular chamber o" is formed in the upper head of the working cylinder - in close proximity to the packing surrounding the piston rod I to be filled with water - for the purpose of preventing injury to the packing by the heated air in the chamber above the piston H -

The working cylinder is made in two parts of about equal lengths - and has interposed between them two cupped packing rings o⁵ - and o⁶ - and the metal ring o⁷ - all arranged and secured in position before bolting said two parts of said cylinder

together - with the cupped portions of the packing rings - turned in opposite directions - all as shown in Fig - 24 -

Each part of the working cylinder has formed therein - in close proximity to the packing rings $\underline{e}^5$ and $\underline{e}^6$ - an annular water chamber $\underline{e}^8$ or $\underline{e}^9$ - through which water circulates to prevent the transmission of heat to the packing from either end of the cylinder -

A modified form of the engine may be constructed by employing two reversers and two double acting working cylinders - each such working cylinder being constructed in a similar manner to that of the modification shown at Figures - 23 and 24 - where only one double acting working cylinder and two reversers are shown -

In this modification connections must be made by pipes or otherwise so that the heated end of each reverser is connected with both the lower end or space beneath the piston of one working cylinder and the upper end or space above the piston of the other working cylinder -

This modified form would have the advantage over the form described - in which two reversers and two single acting working cylinders are combined - that for exerting the same power - working cylinders of lesser diameter having only half the area of single acting cylinders may be employed.

Another modified form of the engine may be constructed by employing only one reverser and one single acting working cylinder - thus being similar to the engine shown in the drawings with two reversers and two single acting working cylinders if one reverser and its working cylinder were removed

Such an engine would without further addition - exert its power only during the upward stroke of the piston - and would be applicable in such cases where one sided action only is required - for instance for driving a single acting fist hump: this form could for other purposes be further modified by applying a counterbalance of such weight that one half the power exerted in the upward stroke of the engine

would be employed to raise this same weight - which in the downward stroke of the piston would react or give back the half of the power employed to raise it - thus this modification would in reality be acting in both directions giving regular and uninterrupted power - that is to say - one half each way -

Instead of weights or counter-balances the space above the piston could be made of the proper capacity either by itself or by connection with a suitable chamber to form an air vessel - in which - by the upward stroke of the piston the air would be so compressed as to require one half of the power exerted in that upward stroke to compress it - whilst during the downward stroke this compressed air would react like a spring and give back that one half of the power - and thus the engine would work regularly and without intermission of force one half being virtually exerted for useful effect in the upward stroke by the excess of power in the heated air over and above the power required to compress the air above the piston - and equal force being

exerted in the downward stroke for useful effect by the expansion of the compressed air or air-spring. Such an engine with but one reverser and one single acting working cylinder would be comparatively very simple and cheap.

To heat the air rapidly is one of the main requirements of a successful air engine.

Heaters or heating apparatus to do this effectively must combine the greatest possible heating surface with the least possible contents of air - the air being subdivided as much as possible within such heaters. Of this nature are the heaters shown in the drawings and described in the Specification.

Now all such heaters are liable to rapid injury and destruction by the influence of the heat and oxidation by the fire gases on the one side and the rapid passage of the hot air on the other.

It is therefore important that a metal should be used in their construction which will combine the greatest possible resistance to the heat and oxidation - with a cost not too high as to preclude its employment

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Nickel has been found to meet these requirements.

Having thus described the nature of the said invention and the mode in which the same is carried into effect - we would have it understood that what we claim - is -

1st - In an air engine - a heater composed of a series of tubes set in the cylinderhead in a position to be acted upon by the hot gases from the furnace or other means of ~~abbbying~~ heat - and through which air may be circulated by the movements of the reverser piston substantially as described.

2nd - In an air engine to be operated by alternately heating and cooling the same body of air - a cooler composed of a series of tubes set in the cylinder head - and through which air may be circulated by the movements of the reverser piston, in combination with an enclosing casing surrounding said tubes and adapted to be filled with water substantially as described.

3rd - In ~~an air engine to be operated by~~

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alternately heating and cooling the same body of air - a heater and cooler - each composed of a series of tubes set in the cylinder heads - in combination with a reverser piston adapted to move the air through said tubes - substantially as described.

4th - In ~~an air engine to be operated by~~ alternately heating and cooling the ~~same body~~ of air - a heater or cooler - one or both composed of a series of U shaped tubes or their equivalents - both ends of each of which are set in and communicate through the cylinder head or heads - ~~substantially as described~~.

5th - In ~~an air engine~~ the combination of the cylinders N and P - arranged one within the other with an annular space between them - and having their ends closed by suitable heads - a heater or cooler - one or both composed of a series of U shaped tubes or their equivalents set in said head or heads when one end of each of such tubes communicates with the interior of the cylinder P and the other end of each of said tubes communicates with the annular space between said cylinders - and a reverser

er piston adapted to move the air alternately in opposite directions through said tubes substantially as described.

6th. – The cylinder N closed at its two ends by the heads O and Q in combination with the inner cylinder P resting upon the head O and pressed thereto by a spring or elastic material placed between its upper end and the head Q substantially as described.

7th. – In combination with the cylinder N closed at its ends by the heads O and Q the cylinder P made slightly shorter than the cylinder N and placed therein and concentric therewith – and a packing of rubber or other suitable elastic material placed between the upper end of said cylinder P and the underside of the plate or head Q and resting in an annular groove formed in the upper end of said cylinder P substantially as described.

8th. – In combination with a working cylinder and a reverser composed of two cylinders placed one within the other with an annular

space between them the short tube p.p' projecting from the side of the inner cylinder - and bridging the annular space between the cylinders - and a tube leading therefrom to the working cylinder - substantially as described.

9th - In ~~an air engine~~ the combination of a working cylinder and a reverser cylinder connected by a tube for the passage of air from one to the other - a throttle valve placed in said pipe - and a governor connected to and adapted to move said throttle valve to control the speed of the engine - all arranged for operation substantially as described.

10th - In combination with a working cylinder and a reverser cylinder connected by an air passage - a throttle valve placed in said passage - a governor connected with and adapted to operate said throttle - and a hand lever adapted to close said throttle against the resistance of the governor, substantially as described.

11th - In ~~an air engine having~~ two working cylinders and two reversers arranged in pairs

two throttle valves placed upon the same shaft - and a governor connected to and adapted to partially rotate said shaft - and thus open or close both of said throttle valves at the same time - substantially as described.

12th - In ~~combination of the chamber~~ as described connecting the top and bottom (or space above and below the piston) - of each working cylinder with a pipe or passage way - in which is placed a throttle valve actuated by a governor - and a valve or cock worked or set by hand - for the purposes described.

13th - In combination with a working cylinder chambered at its lower end, the shield S fitted to said cylinder with an annular space between it and the chambered portion of said cylinder - and supported upon the cylinder head C substantially as described.

14th - The combination of the working cylinder D or D' chambered - as set forth - and provided with the head C - the shield or inner cylinder S fitted thereto with an annular

space between it and the chambered portion of the cylinder, and the springs g' — all arranged and adapted to operate substantially as and for the purpose described.

15th — In a hot air engine the combination of a working cylinder — a long piston adapted to be worked under pressure upon both sides thereof — and packing rings secured to and moving with said piston — and adapted to resist said pressure in both directions — substantially as described.

16th — The regenerator plates b^2 provided with slightly projecting vertical ribs or corrugations with broad plane surfaces between them when used in combination with the cylinders N and P and air heating and cooling devices — substantially as described.

17th — In combination with the cylinders N and P arranged as set forth the regenerator plates b^2 secured to the exterior of the cylinder P — substantially as described.

18th — The combination of a single acting

working cylinder provided with a piston and containing air under pressure upon both sides of said piston - a reverser cylinder - means of applying heat to the lower end of the reverser and means of conveying air from the heated end of the reverser to one end of the working cylinder while the air in the other end of the working cylinder remains at its normal temperature - substantially as and for the purpose described.

19th The combination of a working cylinder provided with a piston - and adapted to contain air under pressure upon both sides of said piston, and to be worked by alternately heating and cooling the air upon one side of said piston - while the air upon the other side of said piston remains at its normal temperature - a reverser cylinder and a furnace or other means of applying heat to the working cylinder and reverser - substantially as described.

20th - The combination of a working cylinder provided with a long piston adapted to be worked by alternately heating and cooling the air upon one side of said piston - while the air

whom the other side of said piston remains at its normal temperature - a reverser cylinder and a furnace or other means of applying heat to the working cylinder and reverser substantially as described

21st The combination of a reverser cylinder - a working cylinder - a pump for forcing air into said cylinders under pressure - and a furnace or other means of applying heat to one end of said cylinders - while the air in the other end of the working cylinder remains at or near its normal temperature - substantially as described.

22nd - In combination with a reverser cylinder provided with a heater and a regenerator - a pipe or passage leading from the heated portion of the reverser cylinder to the working cylinder - substantially as described.

23rd - The use of nickel in the construction of the heating apparatus of air engines - as and for the purpose described.

24th - The outer casing of the reverser or working cylinder furnace made in two or more parts divided in such a manner that one portion may

be removed to give access to the heater, and allow it to be removed without disturbing the other parts of the engine - substantially as described.

25th - In combination with a regenerator of an air engine a water space surrounding a portion of the upper part of said regenerator substantially as and for the purpose described.

26th - In combination with a reverser cylinder provided with a heater and a regenerator - a pipe or passage leading from the heated end of said cylinder to the working cylinder - and a pump adapted to force air into said reverser cylinder under pressure - substantially as described.

27th - In combination with a reverser cylinder provided with a regenerator and a refrigerator, a heater provided with a series of passages leading from the heated end of the reverser cylinder to the regenerator - and adapted to subdivide the column of air moved by the reverser piston into a series of smaller columns - substantially as described.

28th - The combination of two reverser cylin-

ders- each provided with a furnace or other means of applying heat thereto- and two single acting working cylinders - all arranged and adapted to operate substantially as described

29th - The combination of two single acting working cylinders having the spaces above their pistons connected by a pipe or passage, two reverser cylinders having direct communication with the spaces beneath the working pistons- and a furnace or other means of applying heat to the reversers or working cylinders - substantially as described.

30th - The combination of two working cylinders - and two reverser cylinders - with a furnace or other means of applying heat to all of said cylinders - substantially as and for the purposes set forth.

31st - In combination with two working cylinders provided with pistons and adapted to be charged with compressed air above both sides of said pistons- and to be operated by alternately heating and cooling the compressed air above one side only of each of said pistons - a pipe or passage connecting the chan

bers in the cool ends of said cylinders - substantially as and for the purposes described.

32nd - The combination in an air engine of two working cylinders provided with pistons connected to opposite ends of a vibrating beam - and two reverser pistons adapted to alternately change the air from a heating chamber to a cooling chamber, and vice versa - substantially as described.

33rd - In combination with the reverser cylinder N' - and the annular heater N° - the inner cylinder P' extending nearly to the bottom of the annular space between the inner and outer walls of said heater substantially as described.

34th - The combination of the reverser cylinders N' and P' the annular heater N° - and the corrugated plates u - all arranged and adapted to operate substantially as and for the purposes described.

35th - The combination of the working cylinder D - the annular heater D⁵ - the deflector shield S - and the corrugated plates or rings u substantially as described.

36th.— The combination of one reverser and one single acting working cylinder — similar to those of the engine shown in the drawings i.e. with two reversers and two single acting working cylinders — arranged and adapted to operate substantially as described.

37th.— The combination of two reverser cylinders and a double acting working cylinder provided with a long piston — with a furnace or other means of applying heat to each of said cylinders — substantially as described.

38th.— In a double acting working cylinder operated by hot air upon each side of the piston a water chace in close proximity to the packing of the piston rod — substantially as and for the purposes described.

39th.— In combination with a double acting working cylinder of a hot air engine provided with a long piston, a packing for said piston located at or near the centre of the length of said cylinder — substantially as and for the purposes described.

40th — In combination with a double acting working cylinder provided with a piston actuated by hot air applied to each end thereof a packing for said piston located at or near the centre of the length of said cylinder — and an annular water space upon each side of said packing substantially as and for the purposes described.

41st — In combination with a double acting working cylinder provided with a long piston, and two reverser cylinders, a pipe or passage leading from the hot end of one of said reverser cylinders to the lower end of the working cylinder, and a pipe or passage leading from the hot end of the other reverser cylinder to the upper end of the working cylinder — substantially as and for the purposes described.

42nd — The combination of two reverser cylinders and two double acting working cylinders each of such double acting working cylinders being constructed in a similar manner to those of the modification represented at Figs. 23 and 24 — all arranged and adapted to operate substantially as described.

Executed at Boston Massachusetts U. S. A. this Eleventh day of May — 1881.

Witnesses —
C. A. Hemmenway
Walter S. Lombard.

James A. Woodbury
Joshua Merrill
George Cutler.
Edward Franklin Woodbury.

Improved High Pressure Air Engine.

12993

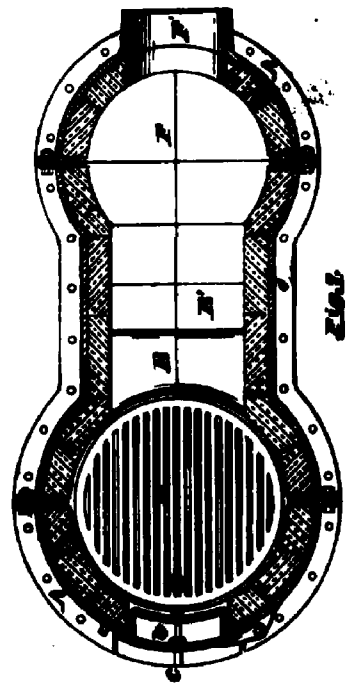


Fig 2.

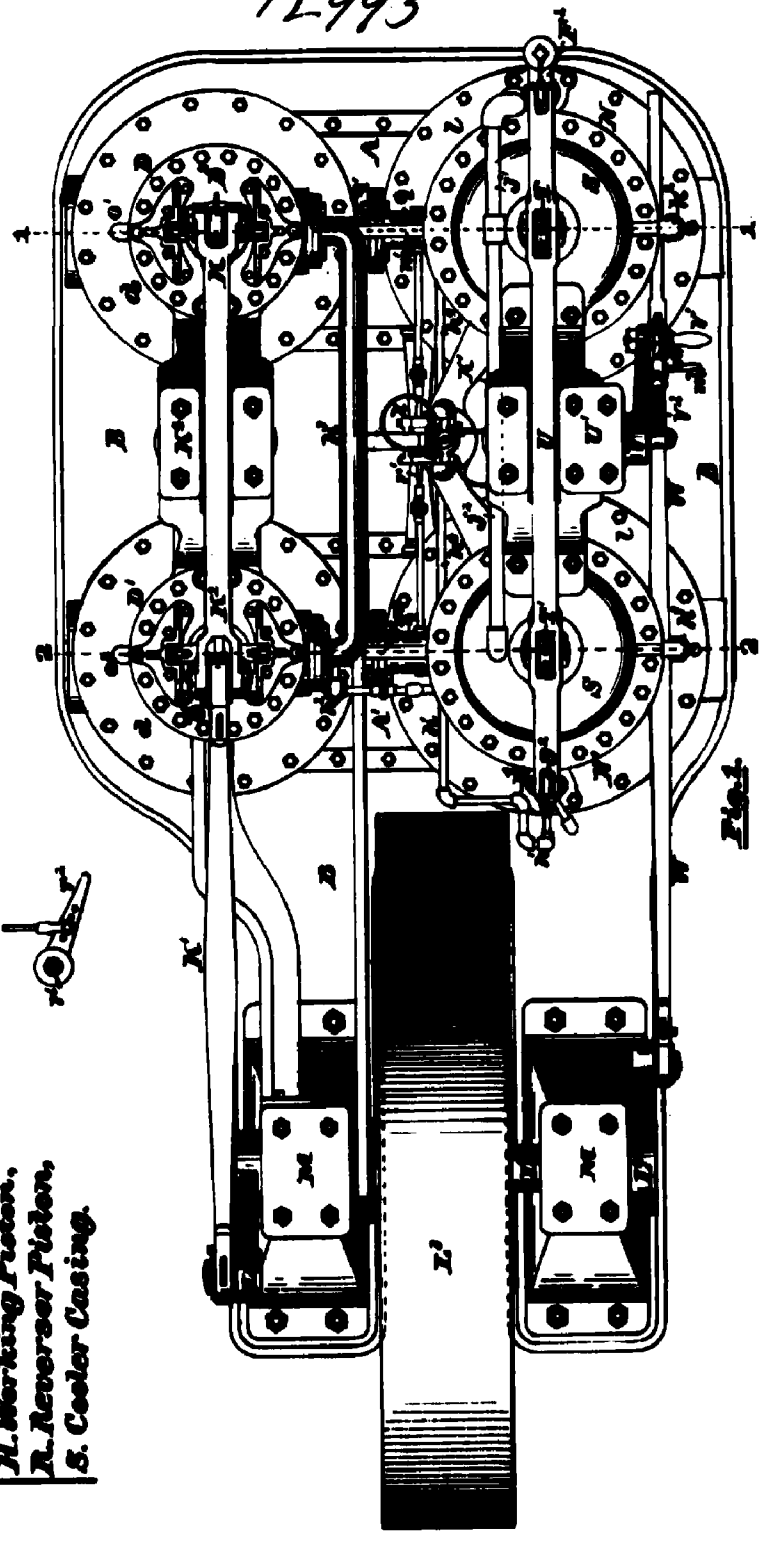


Fig 1.

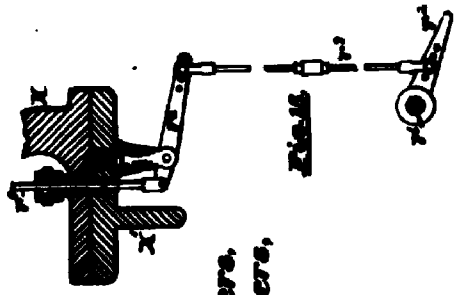


Fig 3.

Reference.

A. Furnace,
B. Bed Plate,
B'. Working Cylinders,
N. Reverser Cylinders,
U. Beams,
X. Governor,
M. Working Piston,
R. Reverser Piston,
S. Cooler Casing.

Ottawa, Ont.
May 20th 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:
L. J. Russelle
L. C. Noël

Inventors:
James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury;
by L. J. Russelle
Attorney.

Improved High Pressure Air Engine.

12993

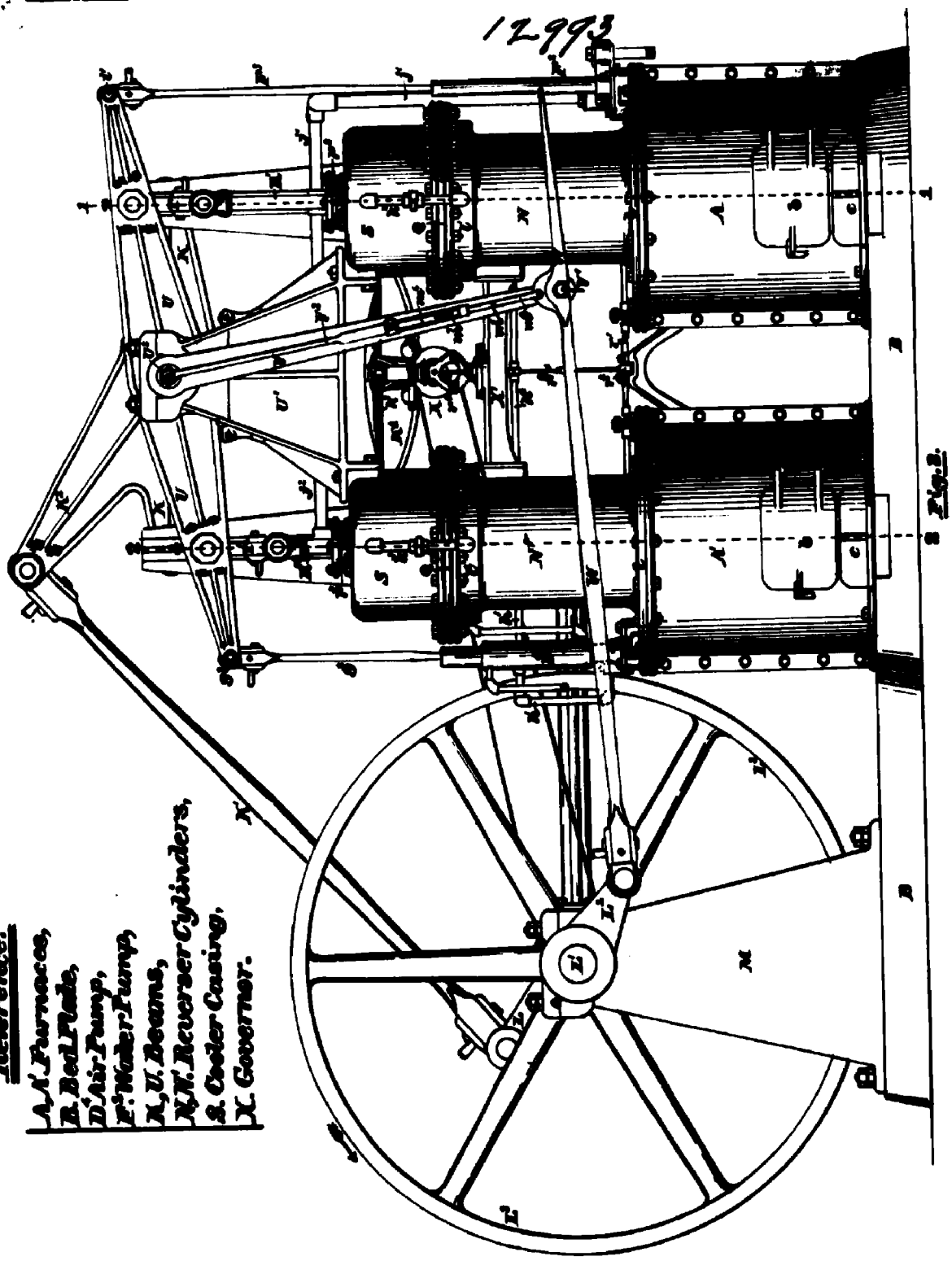


Fig. 2.

Reference.
A. Furnace,
B. Bed Plate,
D. Air Pump,
F. Water Pump,
K, U. Beams,
N, N'. Reverser Cylinders,
S. Cooler Casing,
X. Governor.

Ottawa, Ont.
May 24th. 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:
[signature]
[signature]

Inventors:
James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury;
by [signature]
Attorney.

Improved High Pressure Air Engine.

12995

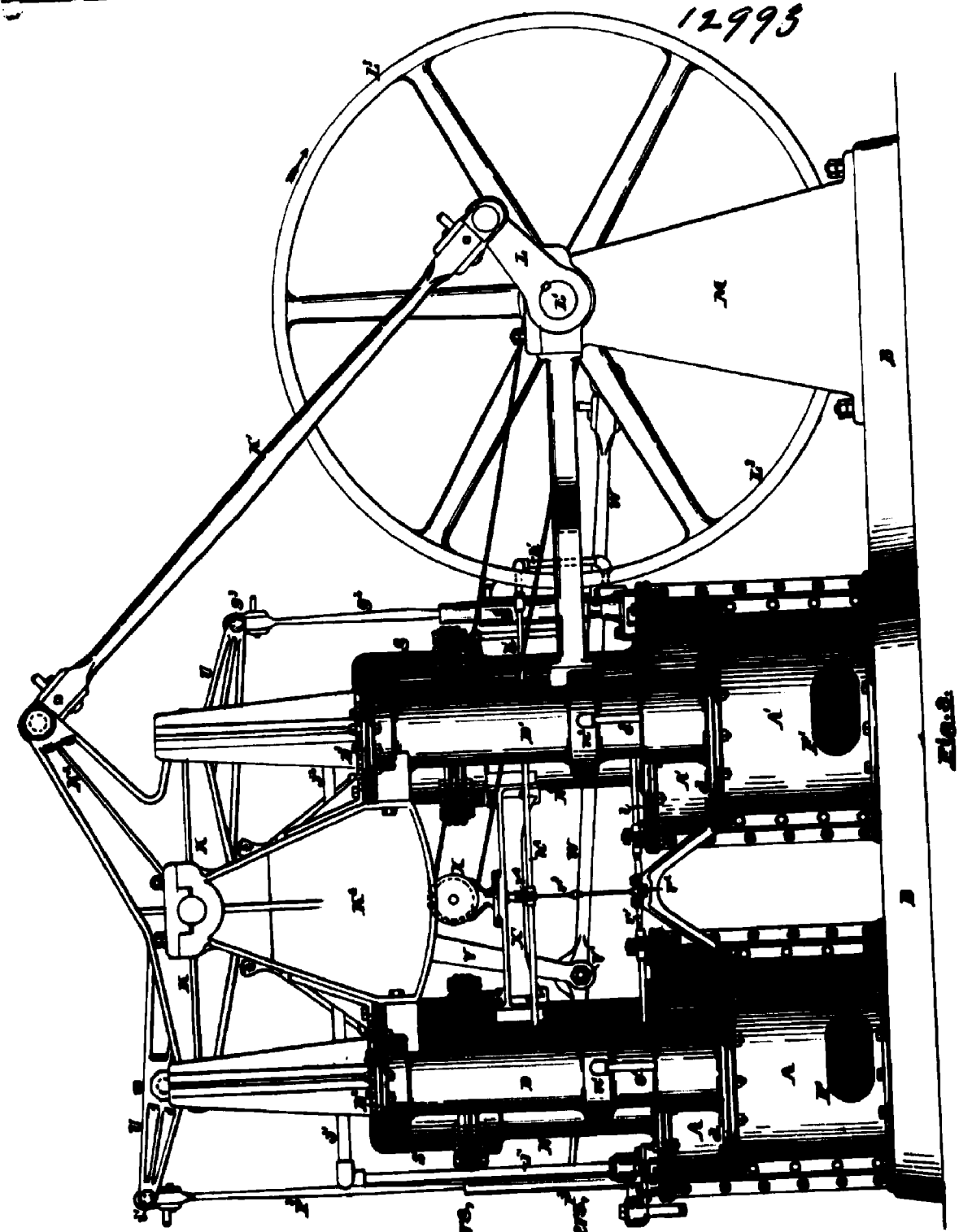


Fig. 1.

References.

A. Furnace.
B. Bed Plate.
B'. Working Cylinders.
D. Air Pump.
F. Water Pump.
K. Beams.
N. Reservoir Cylinder.
S. Outer Casing.

Ottawa, Ont.
May 21st 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:
[illegible]
L. E. Noël

Inventors:
James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury;
by L. J. Forsolus Attorney.

Improved High Pressure Air Engine.

12993

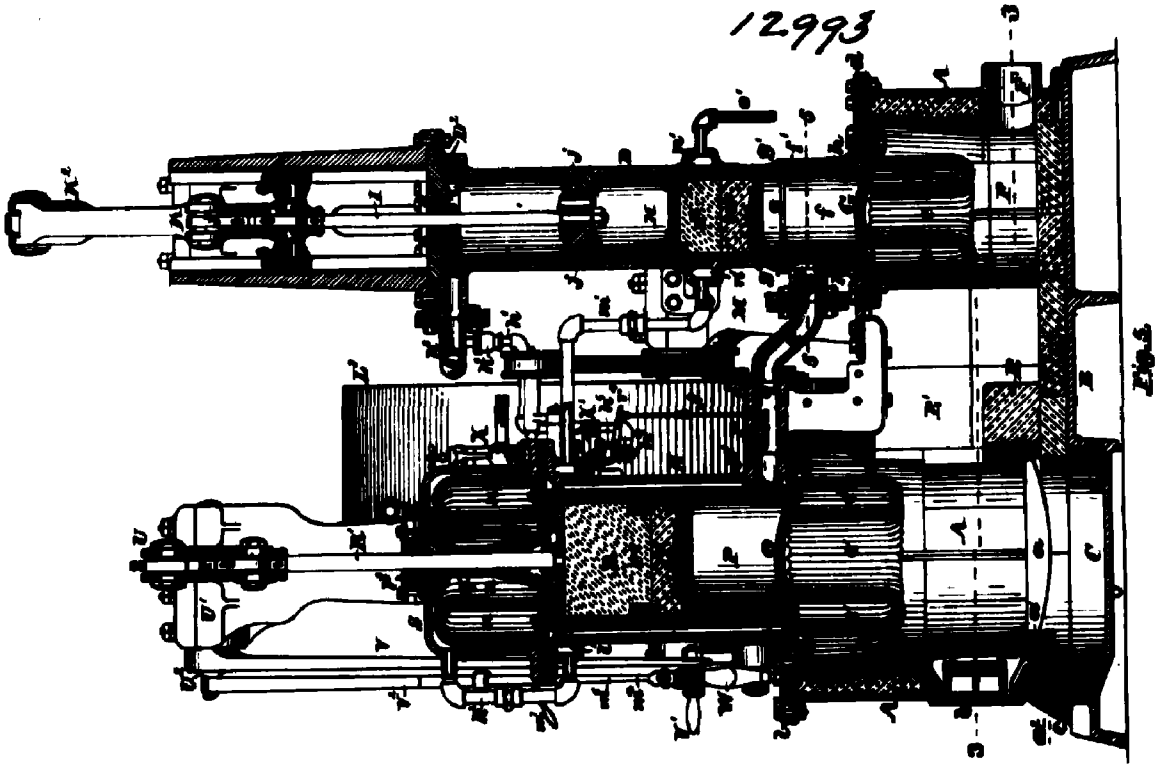


Fig. 1.

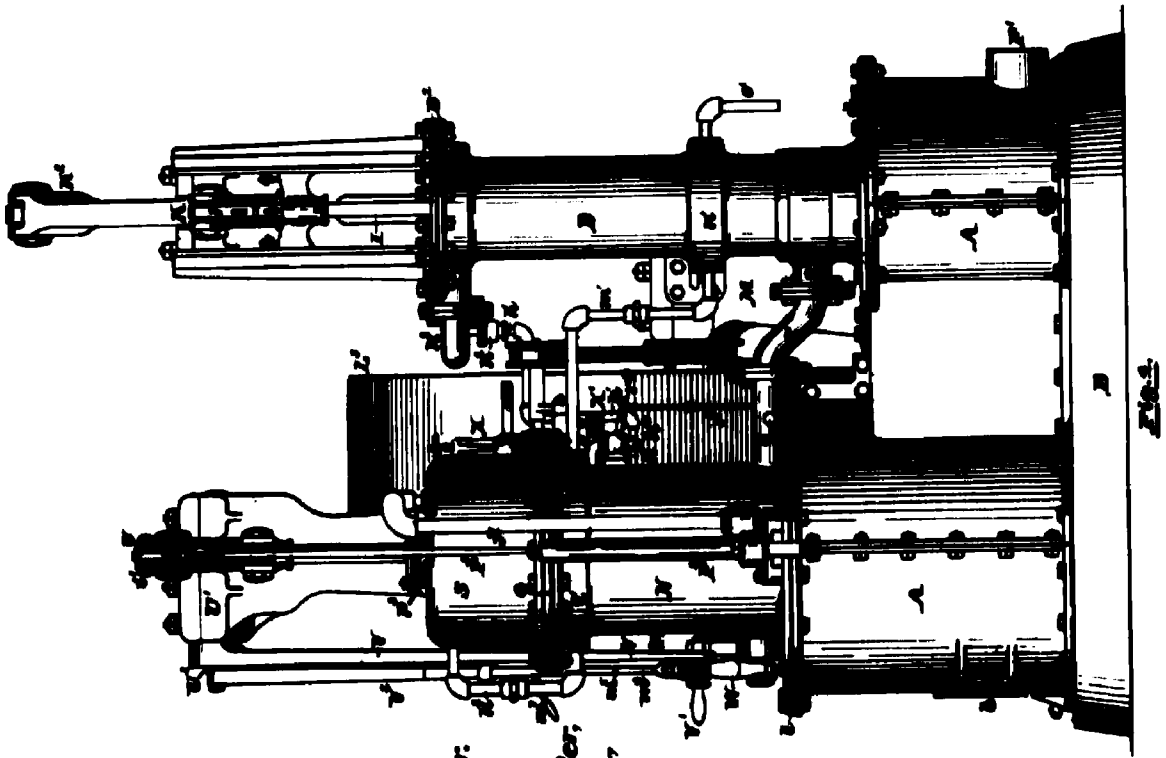


Fig. 2.

Reference.

A. Furnaces,
B. Bed Plate,
D. Working Cylinder.
K. U. Beams,
H. Working Piston,
N. Reverser Cylinder,
R. Reverser Piston,
S. Cooler Casing,
X. Governor,
c.c. Heater Tubes.
x. Cooler Tubes.

Ottawa, Ont. May 2nd 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:

Inventors:

James Atkins Woodbury; Joshua Merrill; George Patten; Edward Franklin Woodbury; by L. J. Arnoldi Attorney.

Improved High Pressure Air Engine.

12993

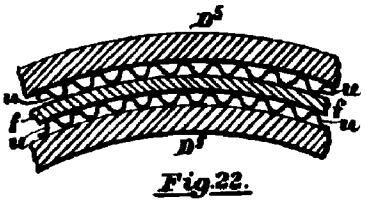


Fig.22.

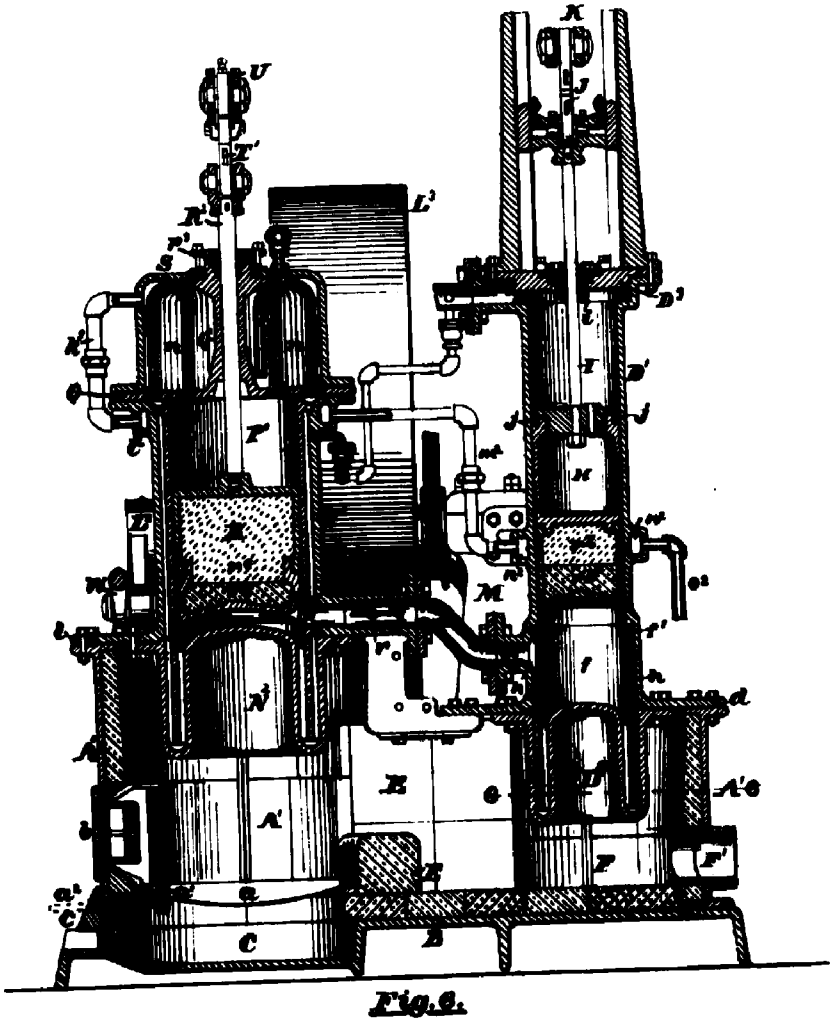


Fig.6.

Reference.

A,A'.Furnaces,	N,N'.Reverser Cyl'r;
B.Bed Plate.	K,U.Beams,
D,D'.Working Cyl'r;	R.Reverser Piston,
D'N'.Heaters.	S. Cooler Casing,
H.Working Piston,	n. Cooler Tubes.

Ottawa, Ont.
May 20th 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:

Inventors:

James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury:
by L.J. Gouraolle
Attorney.

Improved High Pressure Air Engine.

12993

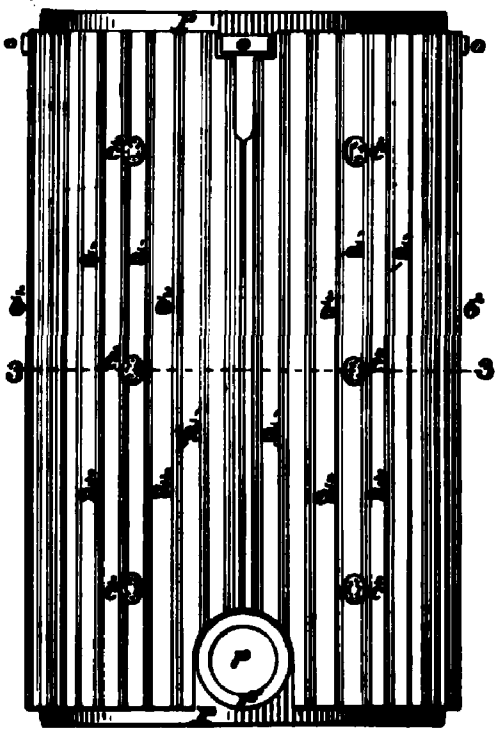


Fig. 10.

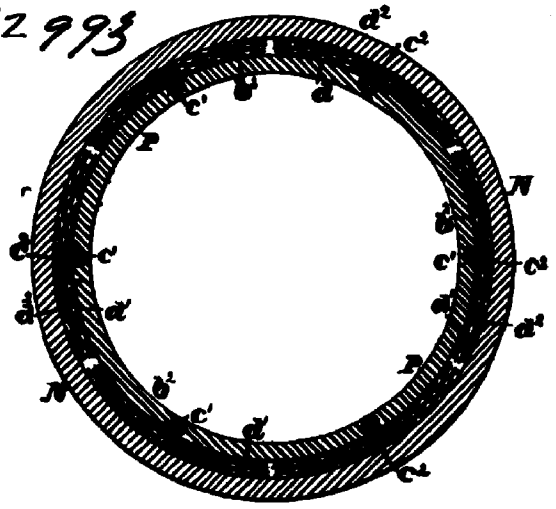


Fig. 12.

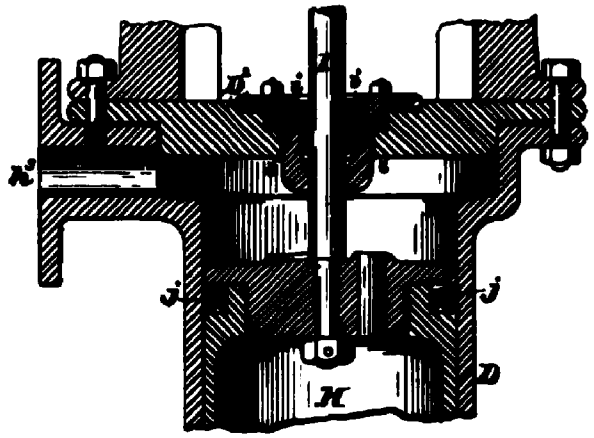


Fig. 9.

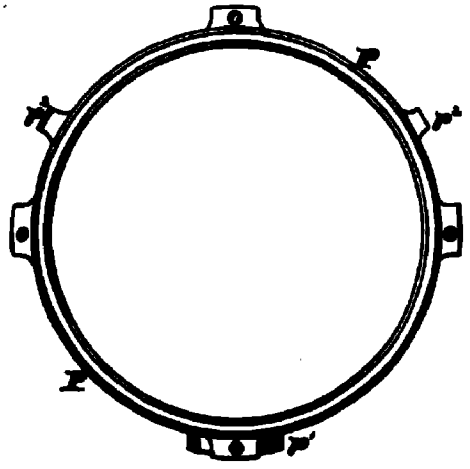
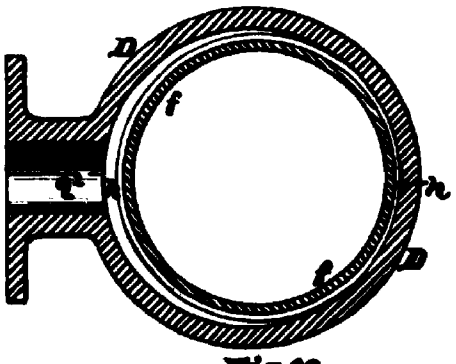


Fig. 13.



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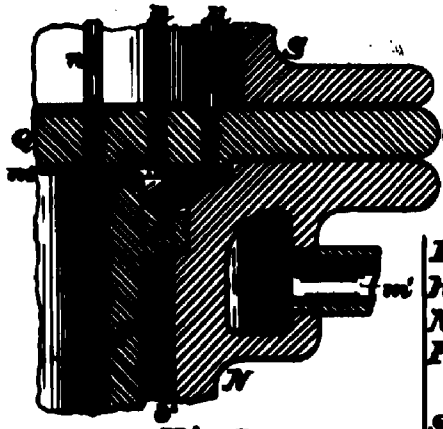

Fig. 8.

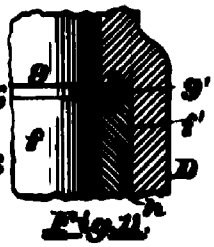

Fig. 11.

Reference.

D. Working Cylinder;
H. Working Piston.
N. Reverser Cylinder;
P. Inner Reverser Cylinder,
S. Cooler Casing,
d^2 Regenerator Plates.

Ottawa, Ont.
May 2d 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:

J. Bousolle
F. C. Mott

Inventors:

James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury;
by L. J. Bousolle Attorney.

Improved High Pressure Air Engine.

12993

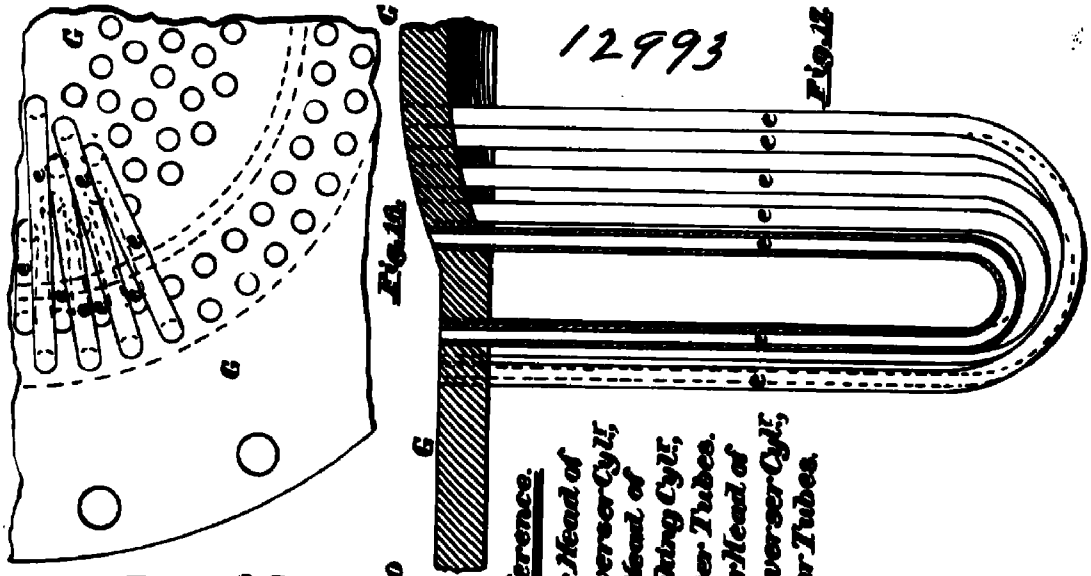

Fig. 1.

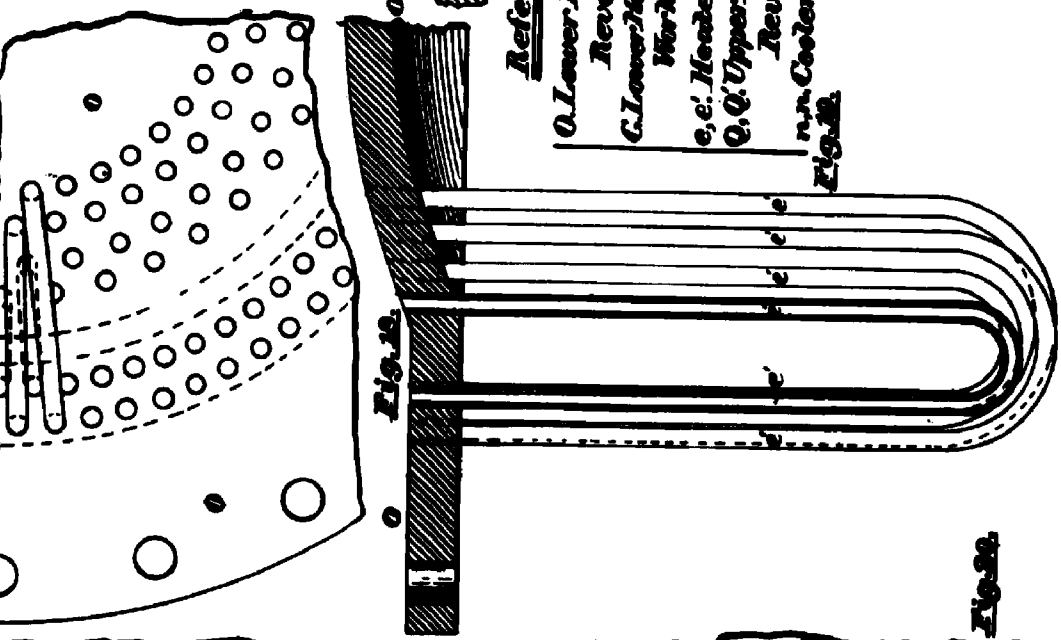

Fig. 2.

Reference.
O. Lower Head of Reverser Cyl;
G. Lower Head of Working Cyl;
e, e'. Heater Tubes.
O, O' Upper Head of Reverser Cyl;
n, n. Cooler Tubes.

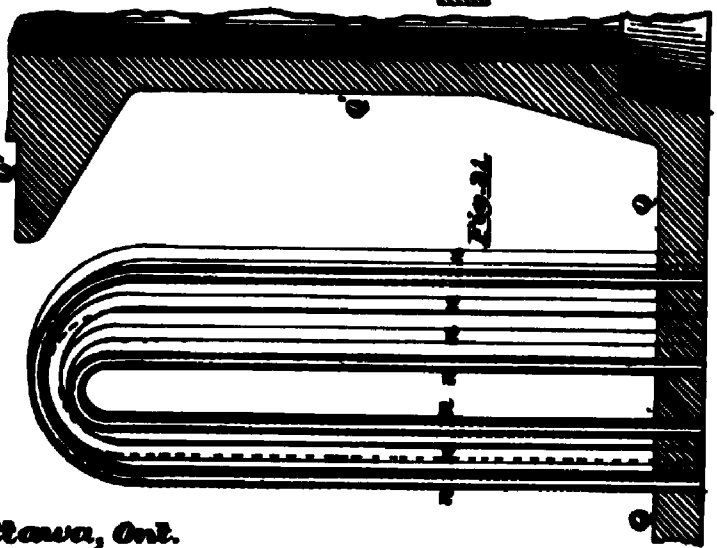

Fig. 3.

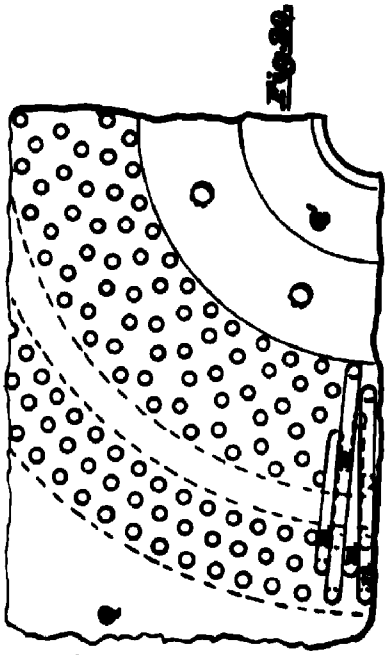

Fig. 4.

Ottawa, Ont.
May 26th 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:
L. C. Mill

Inventors:
James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury;
by L. Fournelle
Attorney.

Improved High Pressure Air Engine.

12793

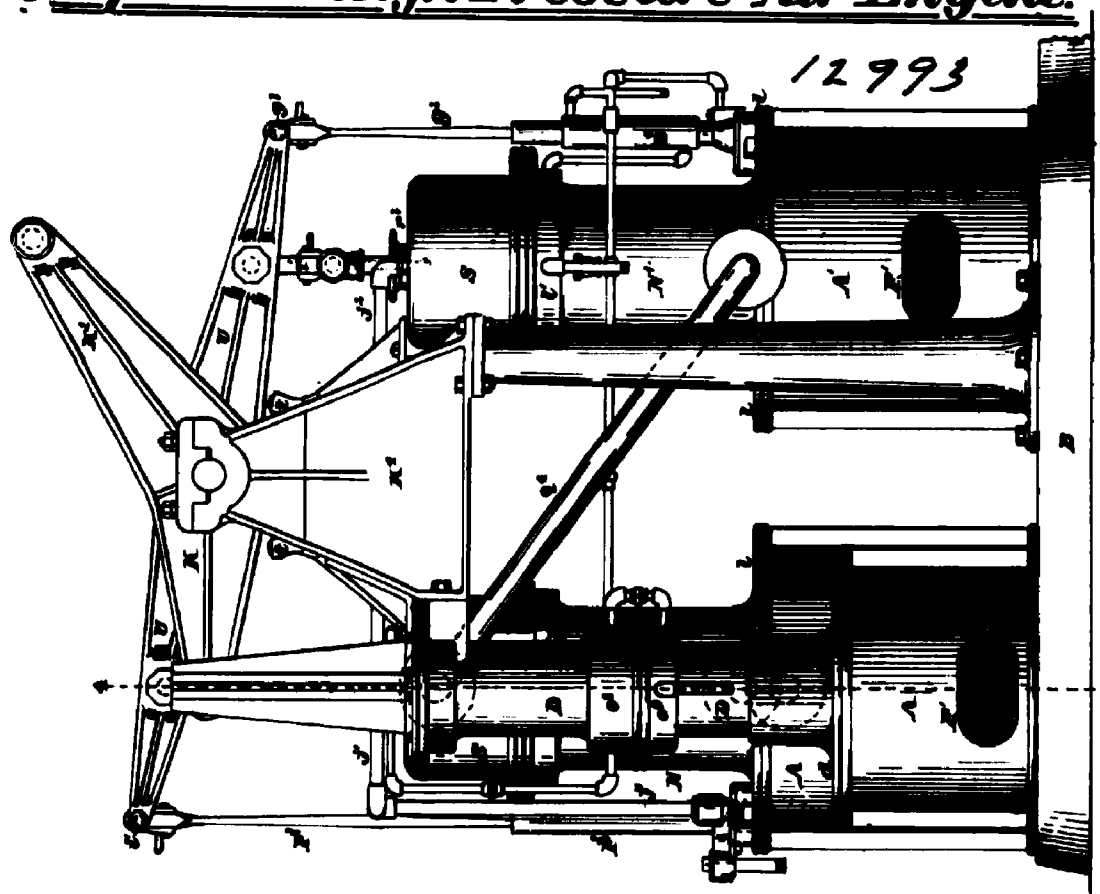

Fig. 22.

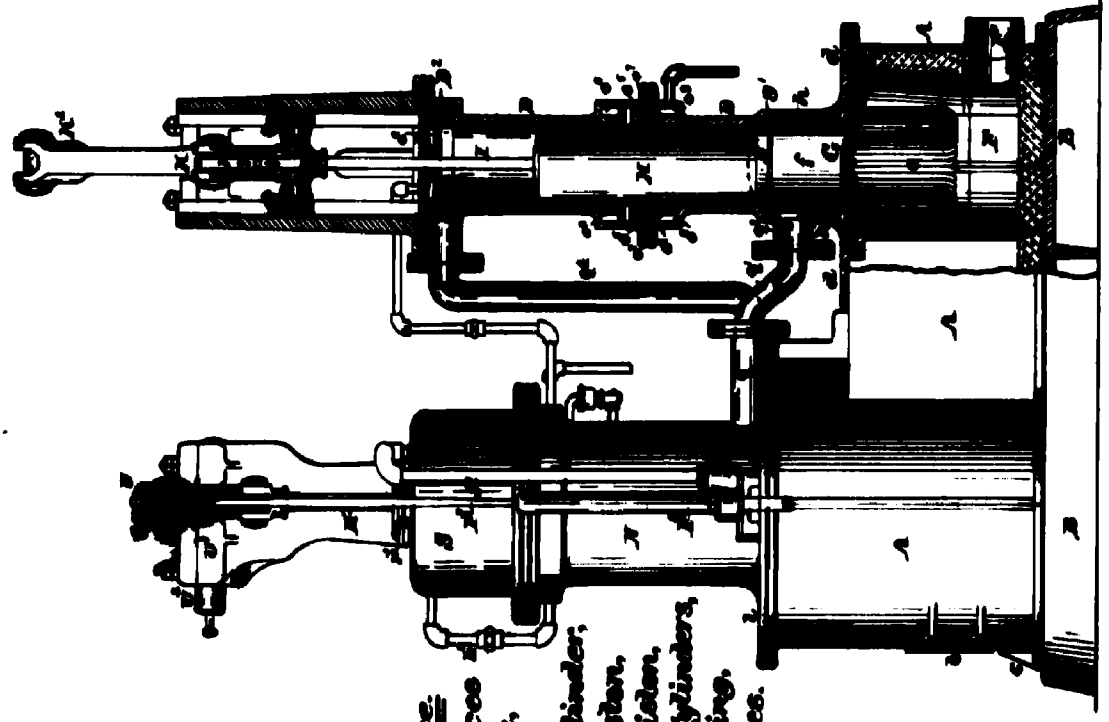

Fig. 23.

Reference:

A. A. Furnaces
B. Bed Plate.
K. U. Beams.
D. Working Cylinder.
M. Working Piston.
R. Reverser Piston.
N. N. Reverser Cylinders.
S. Outer Casing.
T. Heater Tubes.

Ottawa, Ont.
May 20th 1881. Certified to be the drawings referred to in the specification hereunto annexed.

Witnesses:
J. Bourcolle
L. C. Stoll

Inventors:
James Atkins Woodbury; Joshua Merrill;
George Patten; Edward Franklin Woodbury;
by L. J. Bourcolle
Attorney.