(No Model.) 4 Sheets—Sheet 1.

J. S. BALDWIN.

AIR ENGINE.

No. 404,818. Patented June 11, 1889.

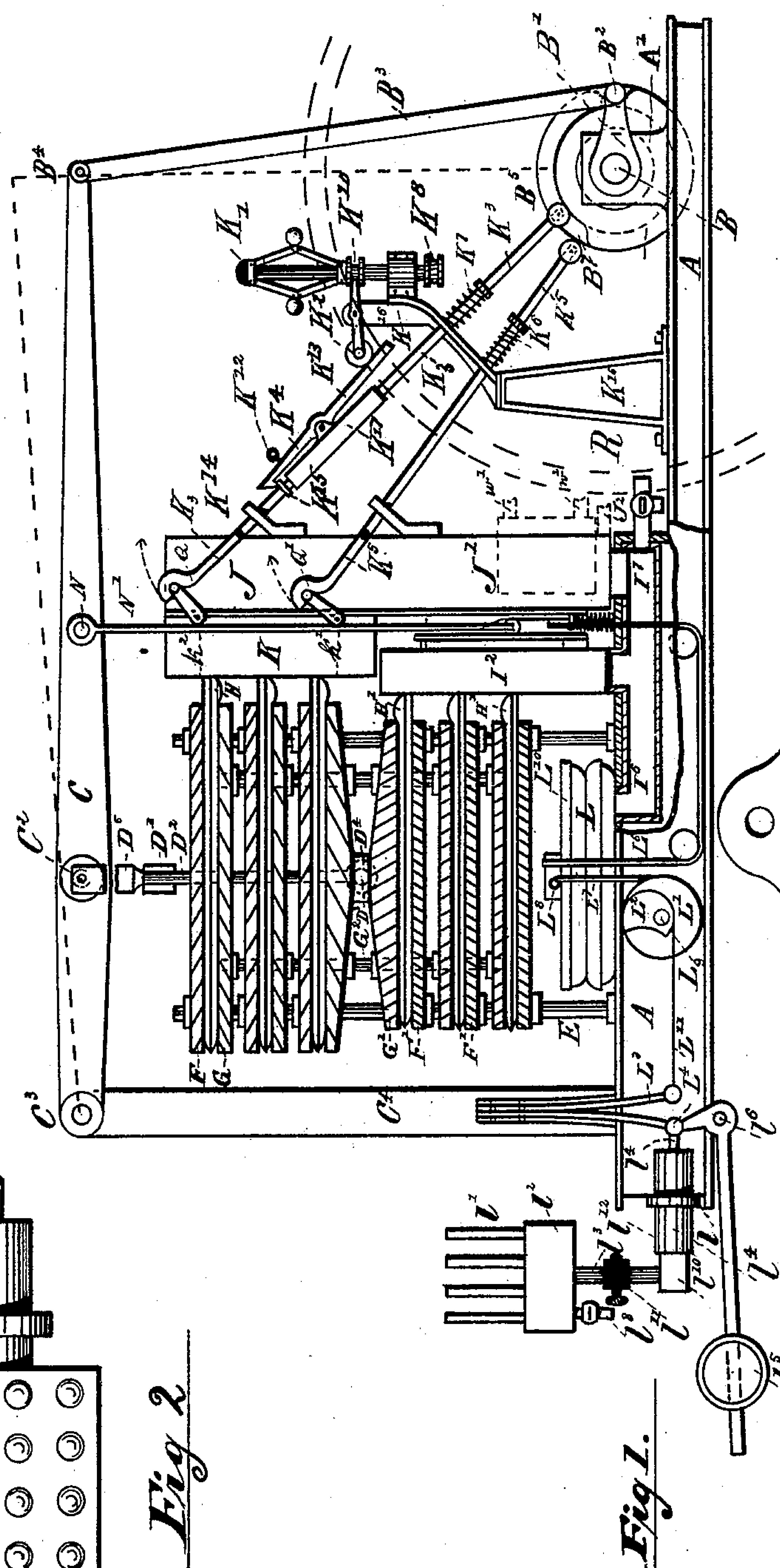

Fig 1.

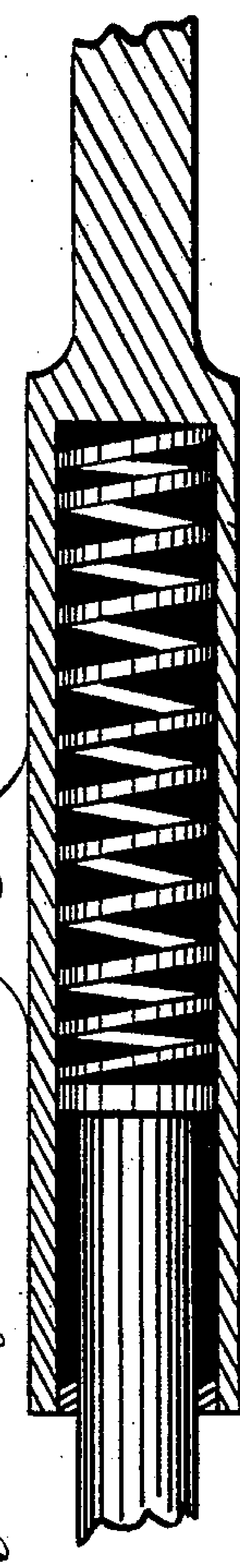

Fig 3

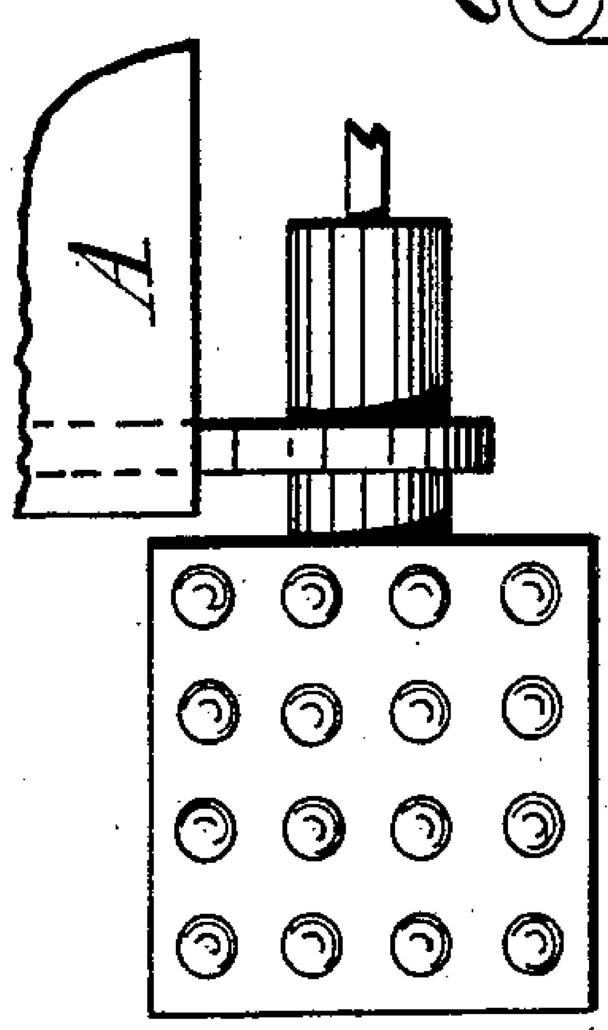

Fig 2

WITNESSES: INVENTOR

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(No Model.) 4 Sheets—Sheet 2.

J. S. BALDWIN.

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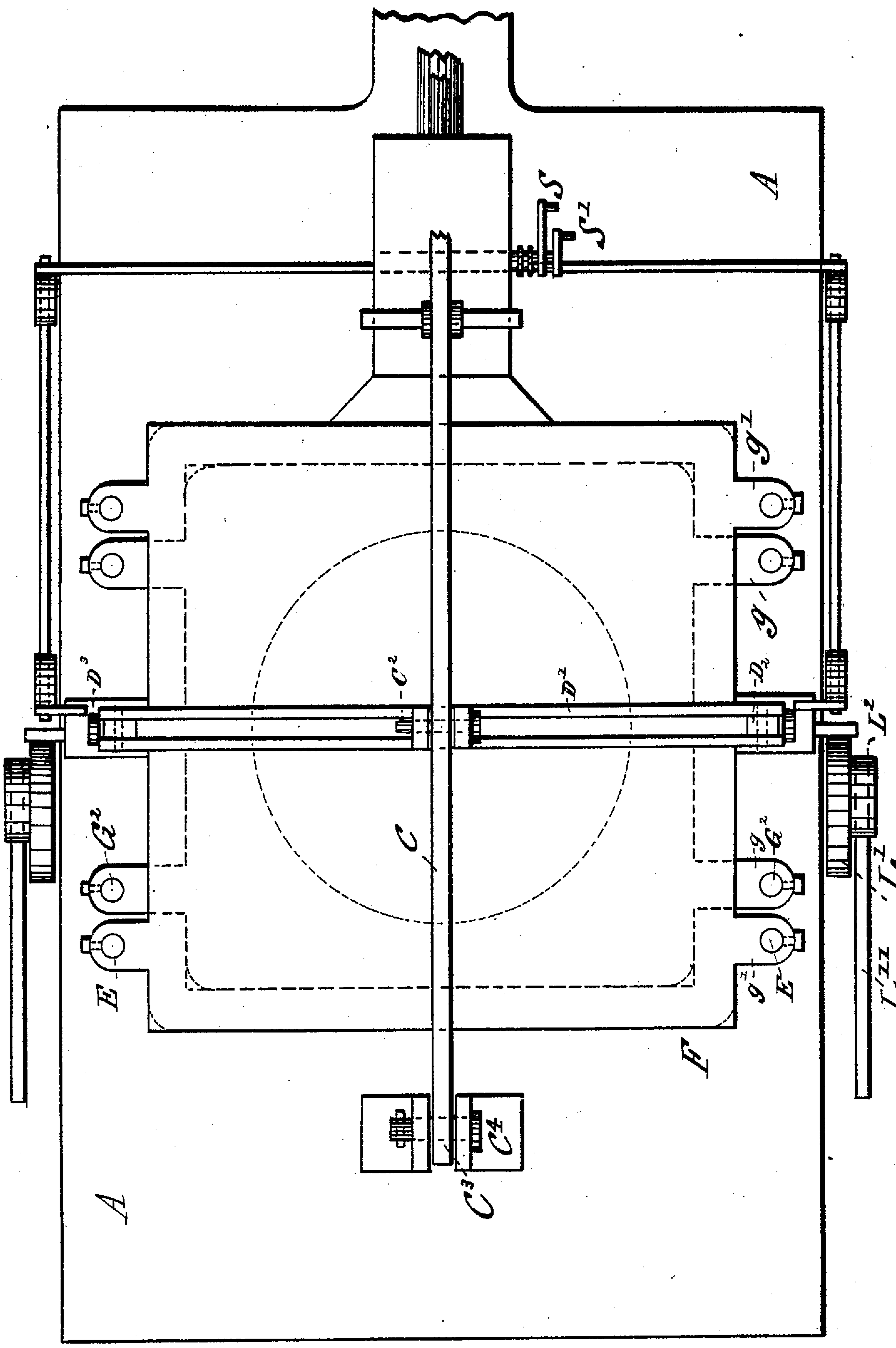

Fig 4

WITNESSES:

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(No Model.) 4 Sheets—Sheet 3.

J. S. BALDWIN.

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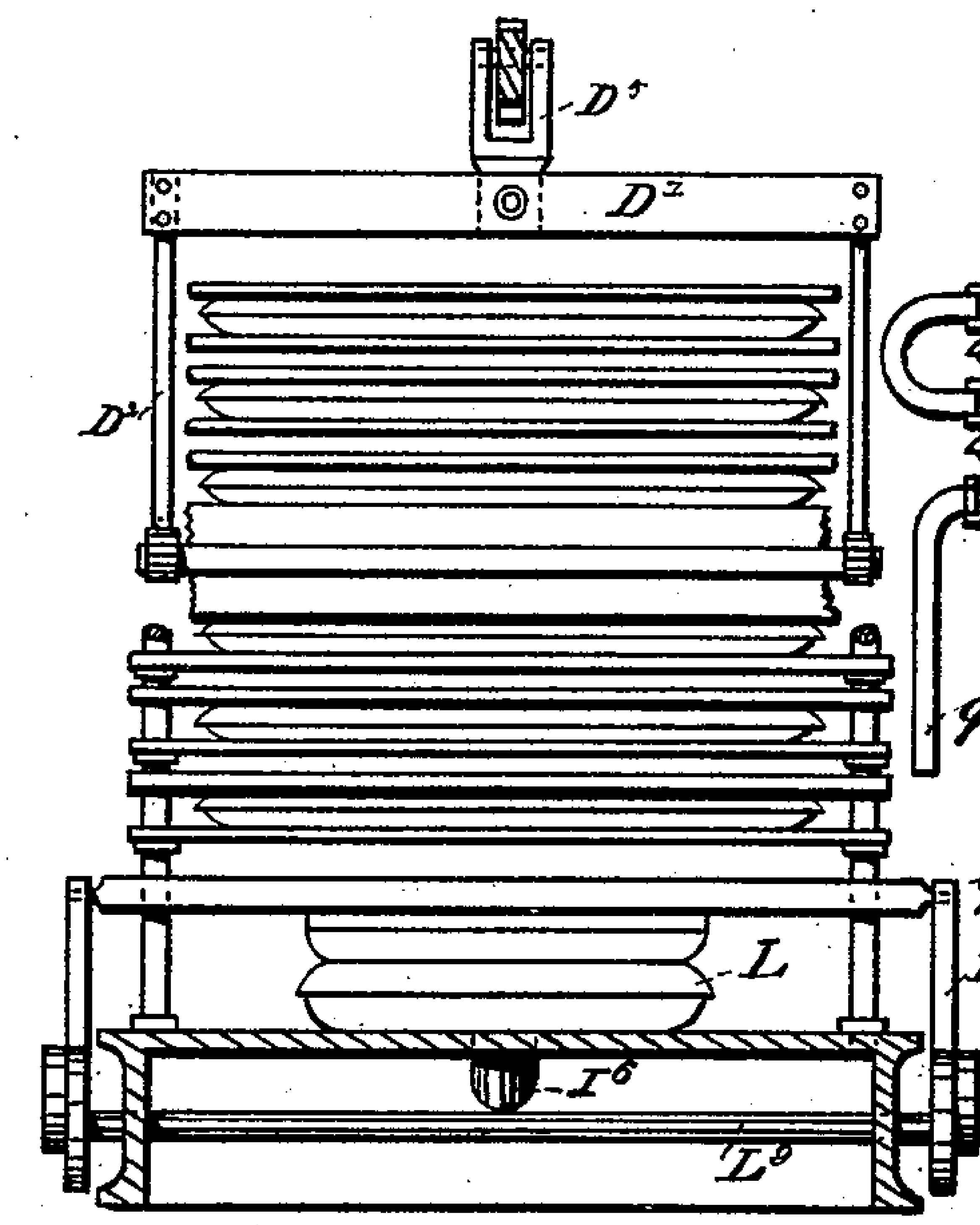


Fig 5

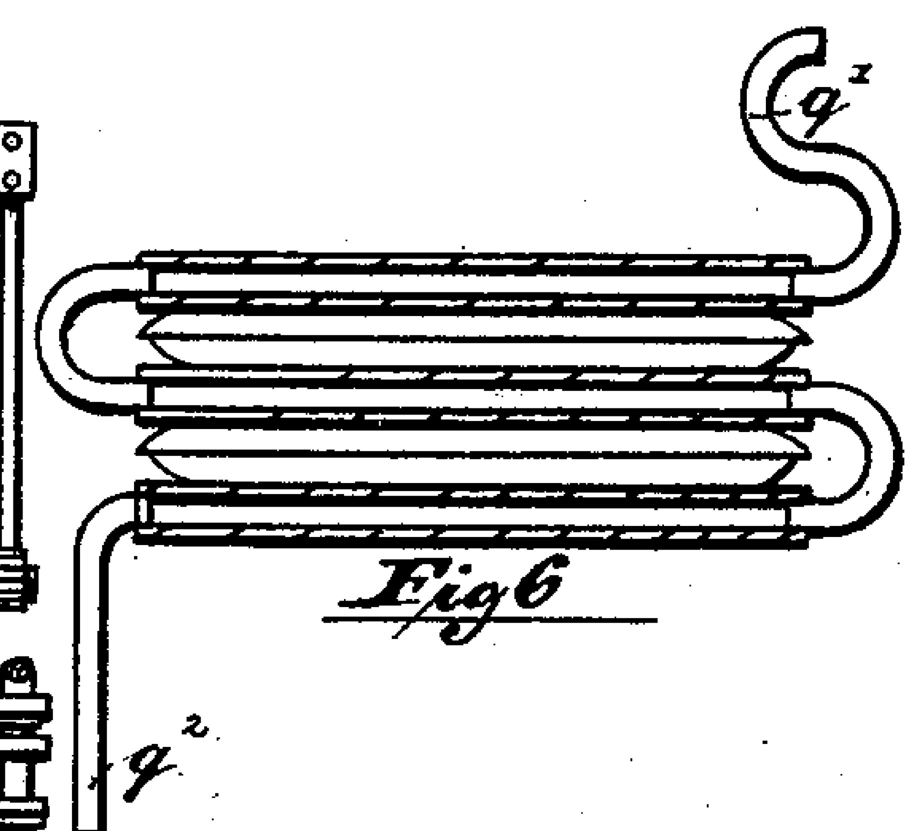


Fig 6

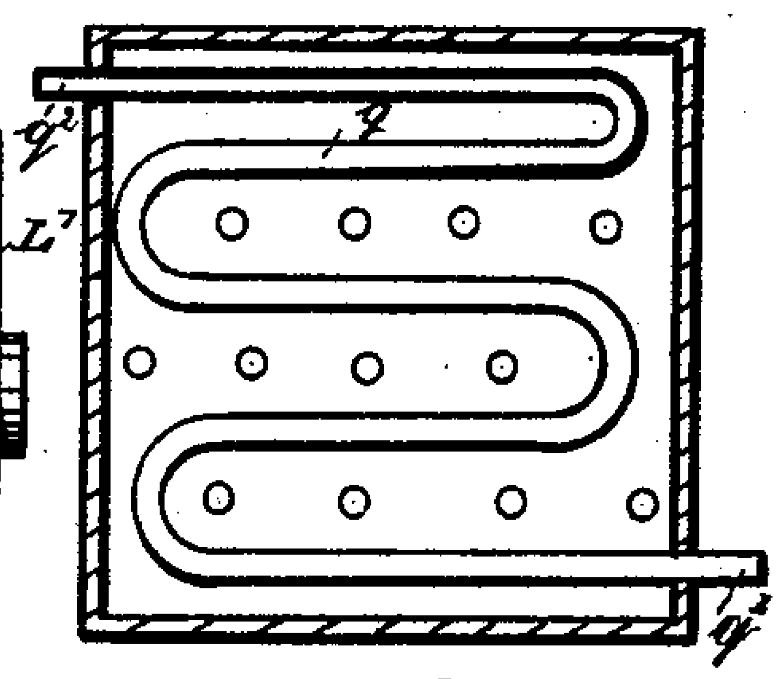


Fig 7

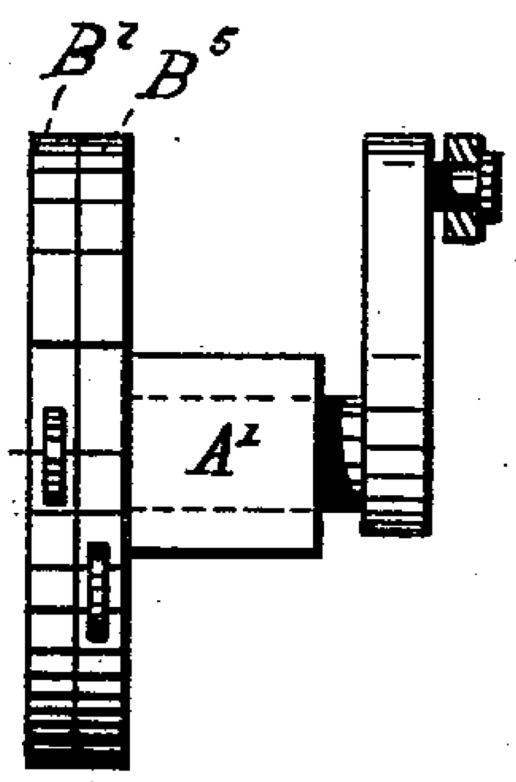
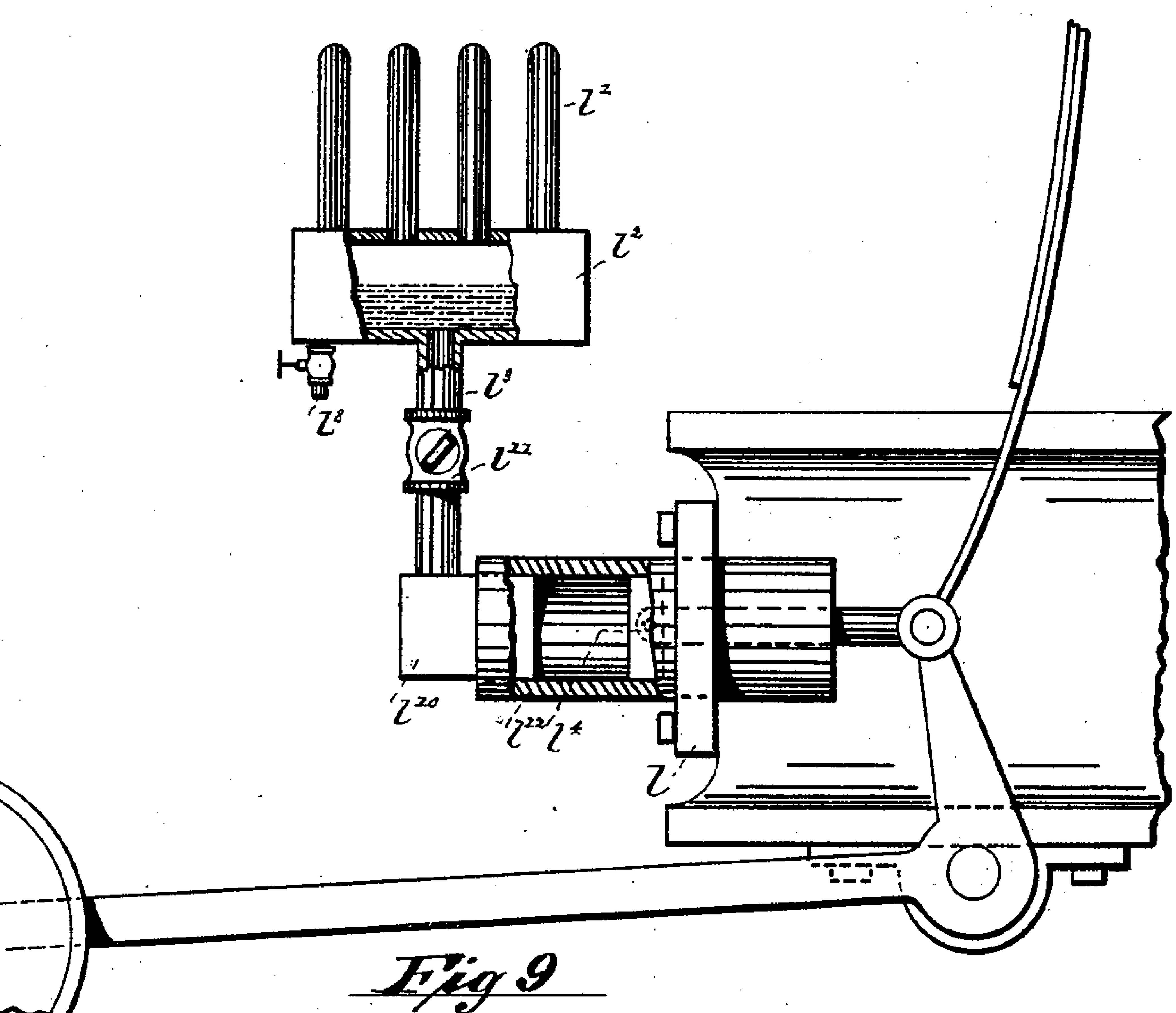


Fig 8



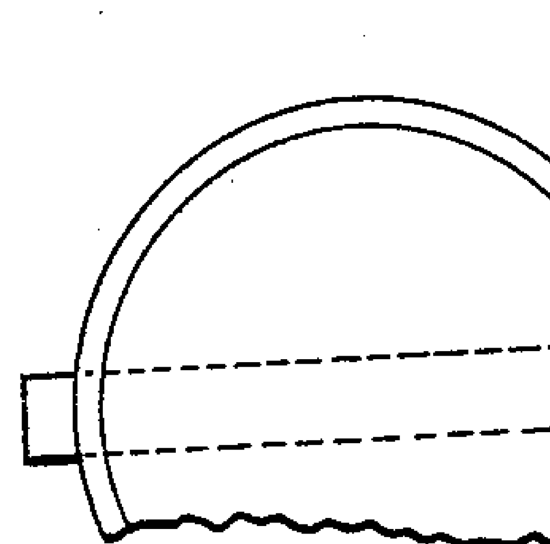


Fig 9

WITNESSES:

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(No Model.) 4 Sheets—Sheet 4.

J. S. BALDWIN.

AIR ENGINE.

No. 404,818. Patented June 11, 1889.

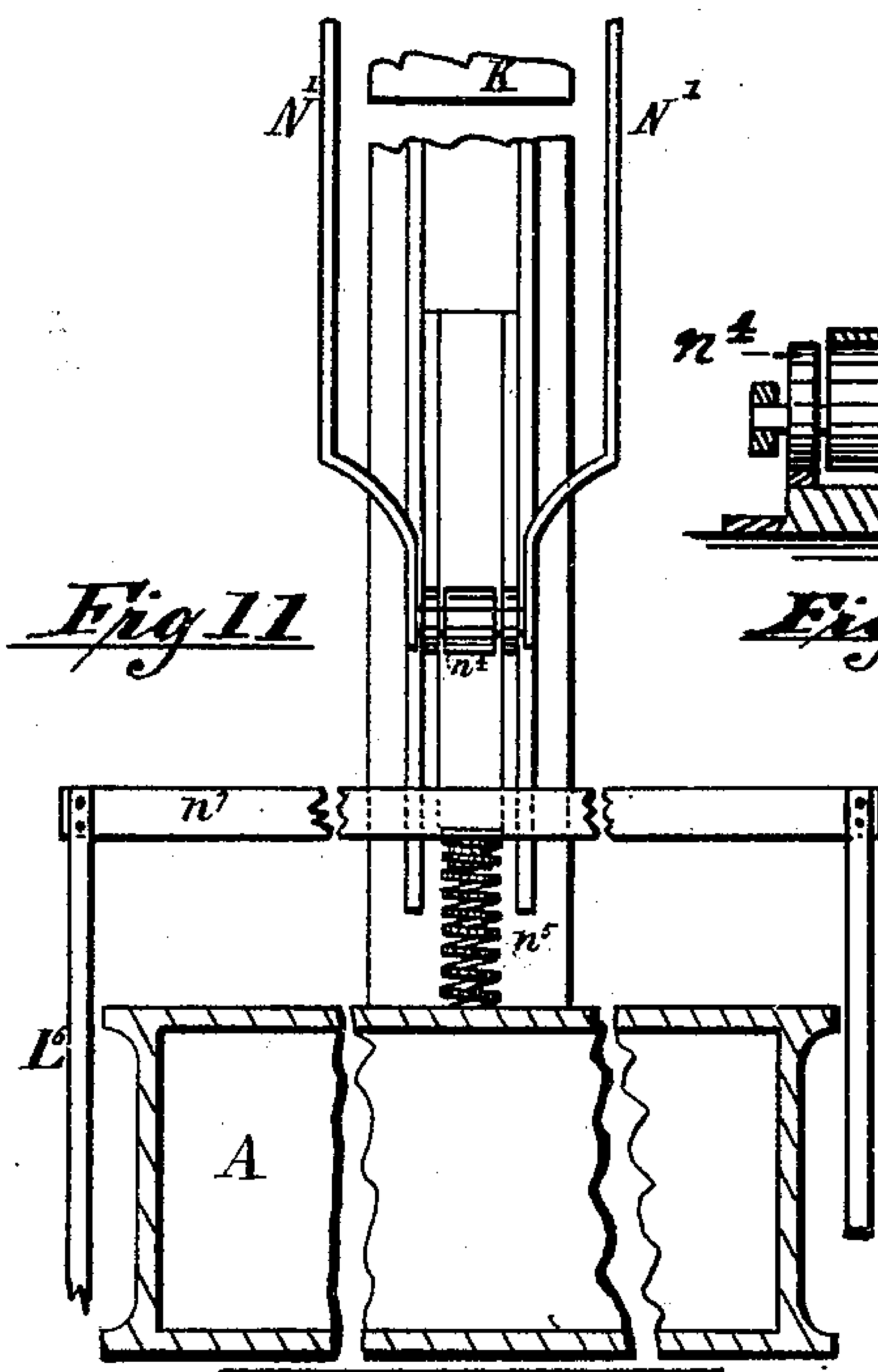

Fig 11

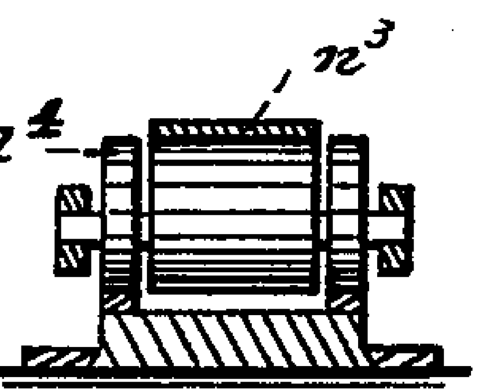

Fig 12

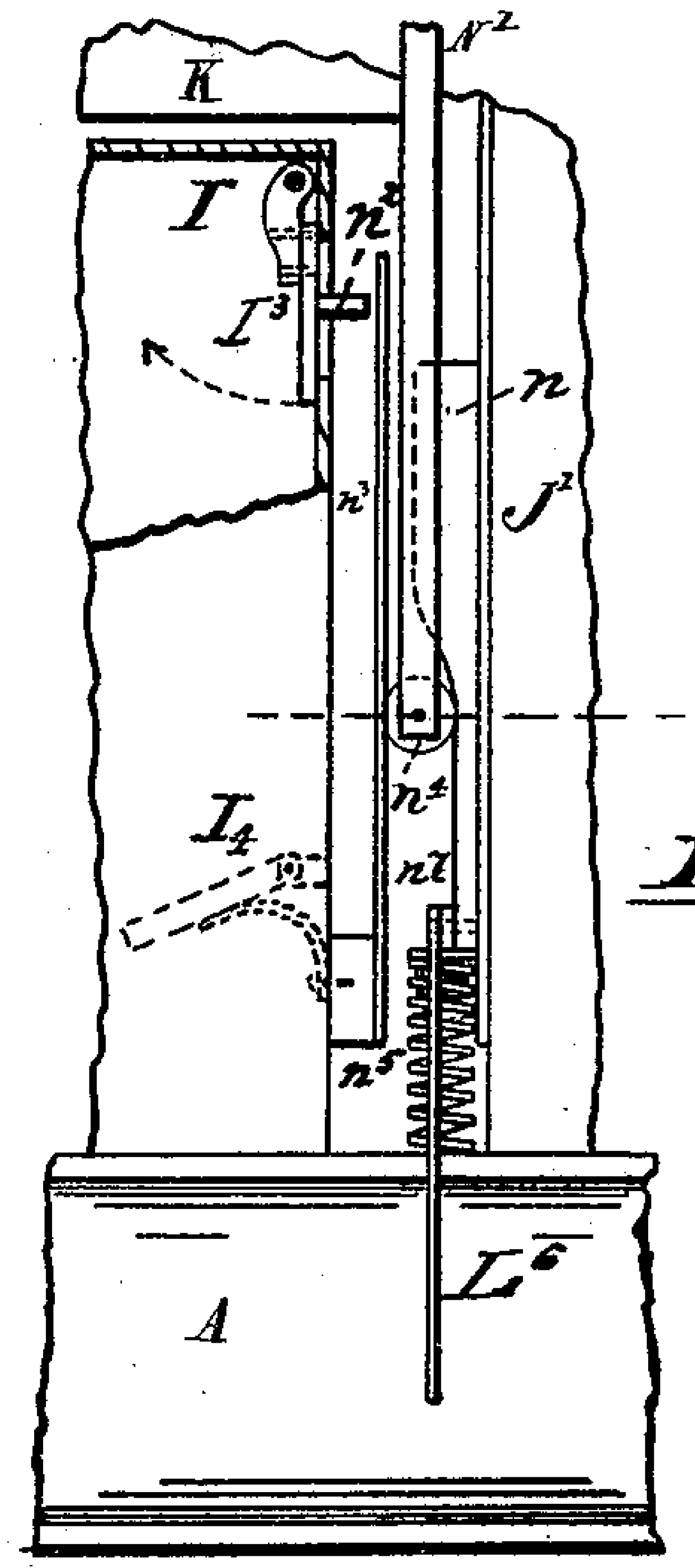

Fig 10

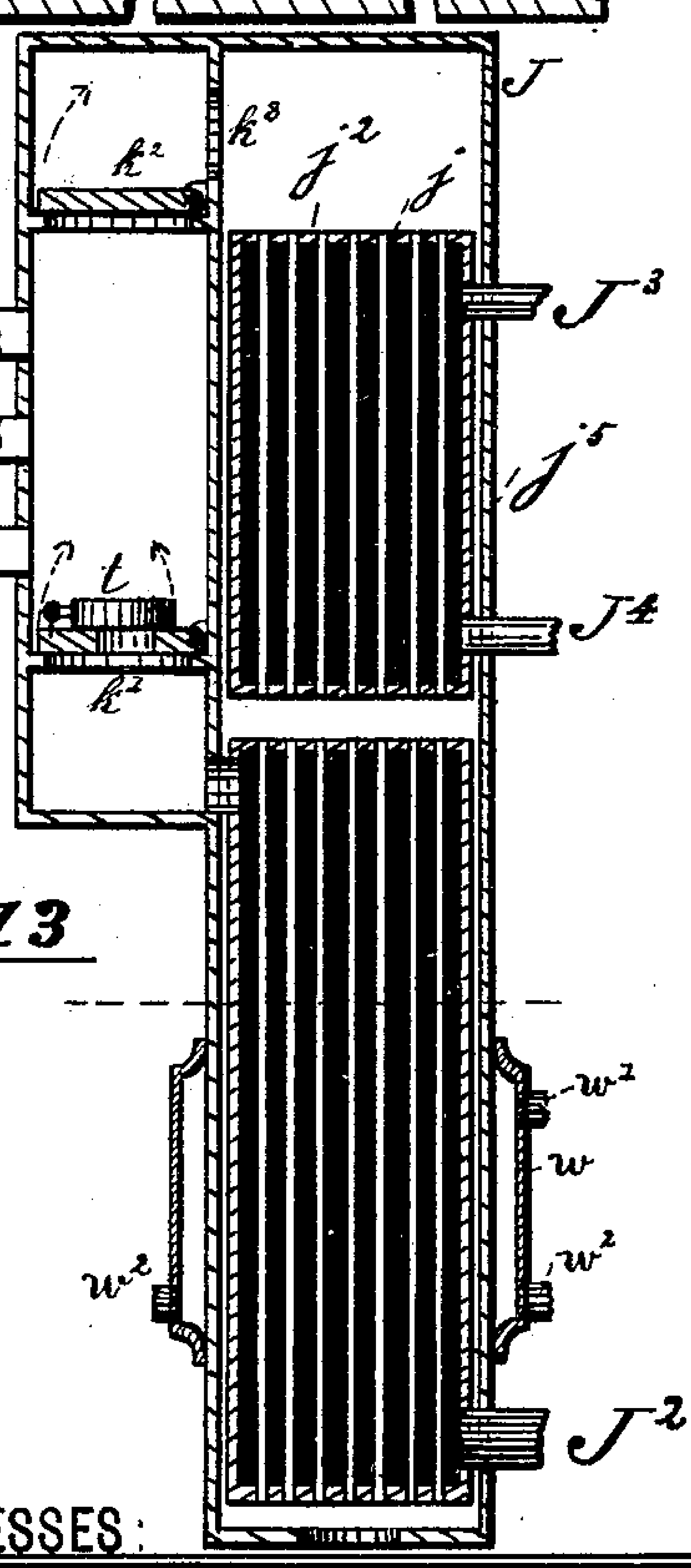

Fig 13

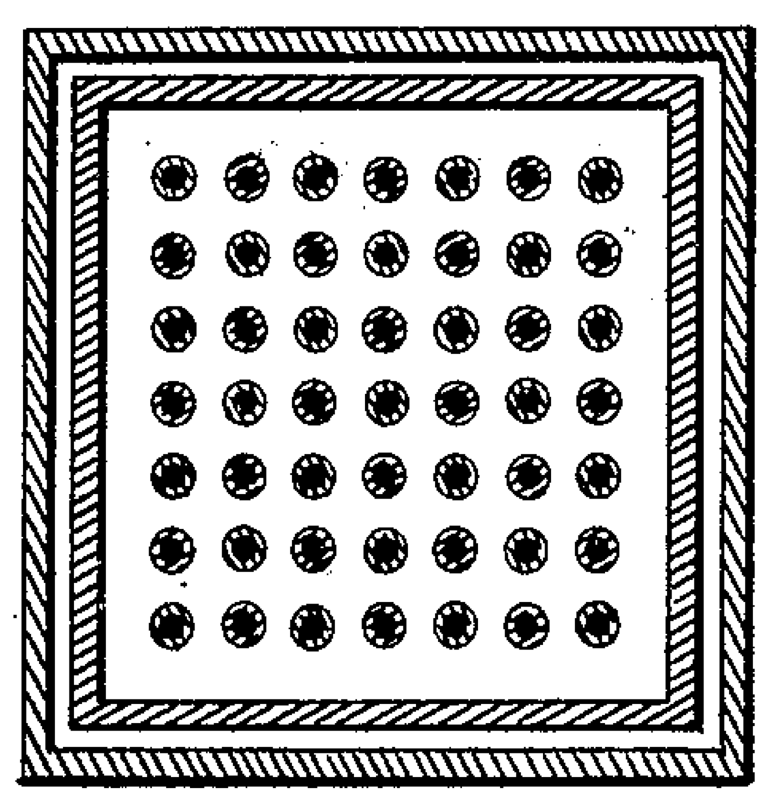

Fig 14

WITNESSES:

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N. PETERS. Photo-Lithographer. Washington, D. C.

UNITED STATES PATENT OFFICE.

JAMES S. BALDWIN, OF NEWARK, NEW JERSEY.

AIR-ENGINE.

SPECIFICATION forming part of Letters Patent No. 404,818, dated June 11, 1889.

Application filed May 19, 1888. Serial No. 274,453. (No model.)

To all whom it may concern:

Be it known that I, JAMES S. BALDWIN, a citizen of the United States, residing at Newark, in the county of Essex and State of New Jersey, have invented certain new and useful Improvements in Air-Engines; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it pertains to make and use the same, reference being had to the accompanying drawings, and to letters of reference marked thereon, which form a part of this specification.

The object of this invention is to secure a larger efficiency and economy than have heretofore been obtained in the conversion of heat, and especially heat of a low temperature, into motive power.

The invention relates to engines which derive their power from the expansion of air or gas; and it consists of certain new or improved processes, devices, arrangements, and combinations that may be employed therein or in co-operation therewith, substantially as hereinafter set forth, and finally embodied in the clauses of the claim.

Referring to the accompanying drawings, embraced in four sheets, in which like letters of reference indicate corresponding parts in each of the several figures, Figure 1, Sheet 1, is a side elevation and partial section of the engine; Fig. 2, a partial plan, enlarged, of a thermal regulator. Fig. 3 is an enlarged sectional view of a portion of a valve-rod. Fig. 4, Sheet 2, is an enlarged plan of a portion of an engine. Fig. 5, Sheet 3, is an end elevation of a portion of the engine with a section of the bed-plate; Fig. 6, same sheet, is a section of a modified form of plates for flexible cells with attached flexible tubes. Fig. 7 is a plan and partial section of a single plate of the same kind. Fig. 8 is an enlarged plan of the cams which actuate the valve, with two detached rollers, showing their position. Fig. 9 is an enlarged side elevation and partial section of a thermal regulator. Fig. 10, Sheet 4, is a side elevation of a pressure-regulating apparatus, with a view of a portion of the interior of the cold-air chest. Fig. 11 is a front elevation of the pressure-regulating apparatus, with a section of the bed-plate. Fig. 12 is a plan and partial section of rollers and co-operating parts belonging to said pressure-regulating apparatus. Fig. 13 is a vertical section of the heater, regenerator, and hot-air valve-chest, with a relief-valve in elevation. Fig. 14 is a horizontal section adapted to represent the structure of either the regenerator or heater.

In said drawings the bed-plate A, pillow-block A′, crank-shaft B, crank B′, crank-pin and box B^2, and connecting-rod B^3, with its working-joint B^4, all have the common and usual functions of such parts in any ordinary engine.

Four rods E, Figs. 1 and 4, are firmly attached to the bed-plate A and sustain the stationary plates F and F′. In Fig. 1 two of these rods are omitted to show other parts more clearly. Facing the stationary plates are a corresponding number of movable plates G and G′. These movable plates are firmly attached to the rods G^2, as shown in said Figs. 1 and 4. All the aforesaid plates are made adjustable on their respective rods by means of suitable lugs *g g′*, Fig. 4, projecting from the opposite edges of each plate and engaging with said rods, the position of the lugs and rods pertaining to the movable plates being such as to allow the simultaneous movement of said plates without interfering with the stationary plates. Both varieties of plates are shown in the drawings with flat surfaces and with edges approximately square; but other forms of surface and outline may be used when preferred.

The central movable plates G and G′, Figs. 1 and 5, are securely bolted to the bar D^4, each end of which forms a stud or wrist D^2, the whole corresponding to the cross-head in an ordinary engine. This cross-head is joined by the connecting-rod D′ D^2 D^5 to the pin C^2 of the beam C, as shown in Fig. 1 and more fully in Figs. 4 and 5. Any impulse communicated to the aforesaid movable plates is by these means transmitted to the fly-wheel of the engine. Between each stationary plate and its adjacent movable plate is or may be interposed a bag or bellows of india-rubber or other suitable material, or in lieu thereof the edges of said plates may be connected by a similar fabric or other suitable yielding material, thus providing in either case a yielding or flexible air-tight cell or chamber. A flexible or yielding chamber as thus constructed will, if supplied with air under pressure, expand, and by its inflation actuate its appropriate movable plate. On the other hand, when such chamber is already filled with air, force applied to said plate will, by compressing the chamber, expel said air.

The three upper chambers H, Figs. 1 and 5, have a larger diameter than the lower chambers H′, and consequently a larger area and displacement. The larger chambers are designed to receive heated air and the smaller chambers cold air. The larger or hot-air chambers are connected by suitable necks with a hot-air chest or header K, and the lower or cold-air chambers in like manner with a cold-air chest or header I^2, in connection with which, and with certain other devices to be hereinafter described, the said chambers are adapted to serve the purpose of a cold-air pump.

In a modified form of hot-air cell or chamber (shown in Figs. 6 and 7) I have provided means for keeping warm the greater part of the walls thereof, in order that hot air entering said cells when the engine is first started may not be cooled and so deprived of its expansive power. In said figures, q are pipes or channels in the body of adjacent plates, both fixed and movable, through which channels steam, hot water, or other suitable heating medium is caused to circulate, thereby warming said plates and their attached or included cells. Flexible tubing or hose q' and q^2 is used where required to place said internal heating-channels in communication with each other and also with appropriate external points of supply and discharge.

Below the cold chambers F′, Fig. 1, is an accumulator L, which consists of an air-tight chamber or bellows, which may be constructed of india-rubber or other suitable materials, substantially in the same manner as the air-tight chambers hereinbefore described. The accumulator rests on the bed-plate A, through which passes the channel I′, opening into said accumulator, and thereby establishing communication between it and a regenerator J′ and a cold-air chest I^2. The accumulator is provided with a head or plate L^{10}, to which is attached a cross-bar L^8. Said bar is controlled by the bands L^7, which are actuated by the concentric pulleys L′, provided with cam-shaped projections L^2. These projections are connected by bands L^{11} to springs L^3.

The springs L^3 are or may be controlled by a tension-screw attached to the bed-plate A and adjusted by the operator to give any required tension in said springs. In place of such means of adjustment, however, I prefer, in the case of large engines, to employ an automatic thermal regulator, as shown in Figs. 1, 2, and 9. The pulleys L′ are firmly secured to the ends of a shaft L^9, and thereby always act in unison with each other, and so maintain an equal pressure on each end of the cross-bar L^8.

The form of each cam-shaped projection L^2 is so adjusted to the varying tension of its springs L^3 as during their extension and retraction to secure the required pressure upon the contents of the accumulator during all degrees of its inflation, making no allowance, however, for the varying temperature of the atmosphere.

To provide for these variations, I employ the thermal regulator already referred to, as shown in Figs. 1, 2, and 9 in one of its forms. In said figures, L^3 represents one of the aforesaid springs attached by a working-joint at the point L^4 to the short arm of a bent lever l^6. The shaft or fulcrum of said lever moves freely in the box l^7, which is secured to the bottom of the bed-plate A. The long arm of said lever is provided with a weight l^5, which preferably adjustable weight maintains a constant pressure upon said spring, which tension may be increased or decreased by changing the position of said weight on the arm. To the end of the bed-plate A is secured the flange l of a cylinder l^{12}, which cylinder contains a piston l^4.

A connecting-rod l^9 is attached at one end directly to said piston by a working-joint and at the other end to the joint L^4 of the spring and lever. The cylinder communicates by a chest l^{10}, tube l^3, and stop-cock l^{11} with a closed tank l^2 and sealed tubes l'. This apparatus is adapted to receive through a stop-cock l^8 either atmospheric air, gas, or liquid under pressure; but I usually prefer to employ both gas and liquid, the gas occupying the tubes l', and the liquid the tank l^2 and the spaces below. As thus arranged any increase in the temperature of the atmosphere in contact with tubes l' will expand the gas or liquid in said tubes, and thereby increase the pressure against the piston l^4, impelling said piston toward the spring, and thereby reducing the tension of said spring, and also the tension of the air in the accumulator L and in the hot and cold air chambers. Conversely, any decrease in the temperature of said outer atmosphere will produce an opposite series of results. The tube l^3 is preferably provided with a stop-cock l^{11} to control the flow of the fluid through said tube, and, by reducing said flow to the smallest practicable amount, preventing any vibratory movement induced in the spring by the action of the accumulator from being transmitted, except in a very slight degree, to the weight l^5.

It will be seen that the pressure in the tubes l' tends to decrease the tension of the spring, and the weight on the lever to increase said tension. By means of this thermal apparatus, when once properly adjusted, changes induced in the tension of the spring by the variations in the temperature of the outer atmosphere automatically regulate and control the pressure of the air, both in the accumulator and the hot and cold air chambers, more perfectly than would be done by the care of a skillful attendant.

Each of the two springs L^3 may be provided with a separate thermal apparatus; or one such apparatus may easily be arranged to operate both of said springs.

The cross-bar L^8 is connected at each end by the flexible bands L^6, running over pulleys L^5, to another cross-bar n^7, secured to a sliding block n. The sliding block is arranged to move up and down in gibs attached to the casing of the regenerator J′. A spring n^5 is placed beneath the cross-bar n^7 and tends to force said bar and said sliding block in an upper direction, which movement is controlled and counteracted by the bands L^6, actuated by the pressure of the air in the accumulator. Any movement of the head of the accumulator will therefore induce a corresponding movement of the sliding block n, the latter descending as the former ascends, and vice versa. The face of the sliding block forms at its upper parts a curved projection adapted to act upon a roller or set of rollers n^4, Fig. 12, said rollers being carried by a double connecting-rod N′, Figs. 1, 10, 11, and 12, which passes upward and over opposite sides of the hot-air chest K to the beam C, to which it is attached by the pin M. The roller is thus caused to move upward and downward with each upward and downward movement of said beam.

An inlet-valve I^3 is arranged within the cold-air chest by means of a hinge i, and is provided with a projecting stud n^2. Said valve opens freely to admit the external atmosphere to the chest I^2 and the cold-air chambers H′ while said chambers are opening. As soon as the chambers are full of air the valve closes by its own weight, and thereby prevents any outflow through said inlet. The flat spring n^3 is secured to the outer casing of the cold-air chest and extends upward between the roller n^4 and the stud n^2, not touching the latter except when impelled against it by the action of said roller and sliding block n.

The capacity of the cold-air chambers, and also of the accumulator, is such as would supply an adequate volume of air to the hot-air chambers at the highest range of the atmospheric temperatures. Whenever, by reason of a decrease in said temperature or for any other cause, the amount of air entering the accumulator would be in undue excess of that required by said hot-air chambers, its effect would be to cause the head of the accumulator to ascend and the sliding block n to descend slightly beyond their normal range, thereby impelling the roller n^4 in its descent against the spring n^3, bringing the upper end of said spring against the stud n^2, and thus holding the inlet-valve open during such portion of each stroke as would allow the surplus air to pass out through the said inlet-valve, and thereby automatically regulate the amount of air retained to that required by the engine.

The cold-air chest I^2 is provided with a check or outlet valve I^4 opening downward and supported on its under side by a light spring. This valve is shut while the cold-air chambers are receiving air and is held closed by said springs and the upward pressure of the air from the accumulator acting against the under side of said valve. When the cold chambers are expelling their air, the pressure of the air-current is sufficient to overcome the pressure of the air from the accumulator, thereby opening said valve and permitting a part of said current to pass into and through the regenerator, and the other part into the accumulator, as indicated by the arrows. The hot-air chest is provided with an inlet-valve or supply k^2, Fig. 13, controlled by rod K^3, spring K^7, and cam B^5, said cam being attached to the crank-shaft B. The rod K^3 is at the appropriate time forced upward by the action of the cam B^5, thereby compressing the spring K^7 and closing the valve. Conversely, by the recession of the cam the spring expands, the rod is drawn downward, and the valve opened. A similar cam B^7, working in like manner by the side of B^5, operates rod K^5 and the outlet or exhaust valve k', Fig. 13. The hot-air chest K communicates with a heater J by an orifice or channel k^8. The hot-air chambers are thus enabled to receive air under pressure through valve k^2 and to discharge said air after its work is done through k'. The latter contains an orifice provided with a smaller secondary valve t, opening in the same direction as the main valve k', and arranged to permit air to pass inwardly to the hot-air chest K whenever a partial vacuum is formed therein, all of which will be understood by reference to said Fig. 13.

The valves k' k^2 are carried by rock-shafts firmly united thereto and passing out through the casing of the chest K, preferably through stuffing-boxes, as shown in Fig. 4. The outer ends of the valve stems or shafts are provided with cranks having studs S S′. These studs are adapted to receive the hooked ends Q Q′ of the rods K^3 K^5, said hooked ends being jointed and capable of being disengaged from said studs when required. These jointed ends are omitted from Fig. 4. Other details may be more clearly shown.

J, Fig. 1, represents a heater, and J′ a regenerator, both contained in the same outer casing, and the interior details of which are shown in Figs. 13 and 14. The outer metallic casing j^5, common to both, contains in its upper part the heater and in its lower part the regenerator. The heater consists of a metallic tube-chamber j, a little smaller in diameter than the said outer casing. Said tube-chamber is provided with an inlet-tube J^3 and an outlet-tube J^4, through which it may receive and discharge steam, hot liquid, or other heating medium. The tubes J^3 and J^4 pass through the outer casing j^5 and into the interior of the tube-chamber j. Said chamber is provided with tubes j^2, extending longitudinally from its lower to its upper head, around which tubes the heating medium can freely circulate.

The regenerator, which occupies the lower part of said outer casing, consists of a similar tube-chamber j', having an inlet k^4, communicating with the hot-air chest K and an outlet J^2, said inlet being adapted to admit the exhaust hot air, which, circulating in contact with the tubes j^3, is discharged through the outlet J^2. All of the various tubes and outlets pertaining to said regenerator and heater are at their passages and joints of attachment made air-tight. The warm air thus discharged from the upper chambers in contact with the tubes j^3 and their casing parts with heat thereto, which heat is in turn imparted to the upward current of air which at the appropriate time is supplied to the said upper chambers, the heater furnishing the balance of heat required to bring said air to the desired maximum, which may be about 210° Fahrenheit.

R, Fig. 1, is a tube provided with a valve for closing the same and communicating with the channel I^7. Through this tube and valve air may either be forced in for the purpose of starting the engine or it may be allowed to escape for any desired purpose.

K^{16}, Fig. 1, is a standard, the upper end of which carries a governor K′, adapted to be driven in the usual manner by a belt running from a pulley on the crank-shaft to the pulley K^8 of said governor. The governor is adapted, when suitably actuated, to depress the roller K^2 when the speed is too high and to raise said roller when the speed is too low.

The valve-rod K^3 has the cylindrical portion or barrel K^{17}, Figs. 1 and 3, provided with a spiral spring adapted to thrust out the prolongation K^{14} of said rod. The thrust of this spring is or may be resisted by a hook K^4 of the arm K^{13}, which hook may engage with and retain the collar K^{15}; but when, owing to too high a velocity of the engine, the governor depresses the wheel or roller K^2 the hook K^4 will be disengaged, and, the collar K^{15} and its attached rod being released, the spring will promptly extend the prolongation K^{14} and close the attached valve k^2, thus cutting off the supply of air from the upper chamber. At an appropriate point in the revolution or in the succeeding one the hook K^4 will be again engaged with the collar K^{15}, said engagement, however, being at all times under control of the governor and its attached roller K^2.

It will be observed that the governor thus automatically regulates the quantity of air supplied to the hot-air chambers.

The operation of the engine is as follows: The hooked end Q′ of the valve-rod K^5, Fig. 1, is disengaged and the exhaust-valve k' is opened, and the fly-wheel is then turned until the crank-pin B^2 is at its highest position. This movement will compress the upper chambers and expel the air therefrom, while at the same time the lower chambers will be open and filled with cold air. Steam, hot water, or other heating medium is supplied to the heater J through pipe J^3, as already described, and to the jacket W of the regenerator and also to the plates of the upper chambers, as shown in Figs. 6 and 7 and already sufficiently described. While these warming operations are in progress a pump or bellows operated by hand or by a small auxiliary engine is connected with a stop-cock R, and the latter being opened air is forced in, inflating the accumulator L and filling all attached channels and other inclosures as far as the valve k^2, which has been left closed and connected with its rod. This operation being complete, the exhaust-valve k' is hooked on and closed, the stop-cock R is closed, and the steam or other heating medium may be shut off from the jacket W. The fly-wheel is now turned sufficiently to throw the crank over the center and bring a receding part of the appropriate cam under the rod K^3, when the latter, impelled by its spring, will open the valve k^2, admitting air under pressure to the upper chambers, which will expand and cause the fly-wheel to revolve. The air thus supplied to said chambers at the beginning of the stroke is furnished by the accumulator L, but when the upper chambers begin to expand the lower ones are to a like extent compressed, and when the air therein contained has reached the necessary tension it opens the check-valve I^4, Fig. 10, and passes through the channel I^7, regenerator J, and heater J′ to the upper chambers. The revolution of the fly-wheel and the downstroke continuing at a point not later than that required to supply four-fifths of the capacity of the upper chambers, a lifting portion of the cam actuates the rod K^3 and closes the valve k^2. The air in the upper or hot-air chambers, being thus cut off from any source of supply, completes its work and the stroke by expanding as an isolated body of air. During this latter part of the stroke the lower or cold-air chambers are at the point of maximum efficiency, and the air which they supply, having no other outlet, is stored up in the accumulator. The downstroke being completed, the fly-wheel continues to revolve and by its momentum effects the return or up stroke, at the beginning of which the exhaust-valve k' is opened by its cam in the manner already described in connection with the supply-valve k^2, and as the upper chambers are compressed the hot waste air is discharged through the said exhaust-valve and the regenerator J′, to which it imparts the greater part of its heat, finally escaping through J^2. The lower or cold-air chambers at the same time draw in air through the valve I^3, Fig. 10, and the completion of the upstroke finds them filled and the exhaust-valve k' closed by the action of its cam at the appropriate time, while the supply-valve k^2 is about to open for a new impulse to be communicated to the engine by the air under pressure, as at the beginning of the first stroke, the air requisite for this purpose having already been supplied to the accumulator by the power of the engine itself, the stop-cock R being now closed. The motion of the fly-wheel continuing and the valve k^2 opening, a new operative stroke will be effected entirely by automatic methods, and being continuously repeated the engine will soon acquire its proper speed and will then be ready for its appropriate work.

The governor K′, &c., Fig. 1, controls the speed of the engine by closing the valve k^2 when the movement is too rapid. Its manner of operation has been hereinbefore sufficiently described. The relief-valve t, Fig. 13, permits air to be drawn into the upper chambers when the supply is cut off by the valve k^2 early in the stroke, and there would be danger of a collapse or a rupture of the flexible chambers if no air could enter. It will be observed that in such a case the air is drawn in through the regenerator, and is consequently warmed, thus avoiding the chilling effect upon the extended internal surface of the upper chambers, or at least the waste of heat which might attend the introduction of cold air.

The engine may be stopped by a disengagement of the hook K^4, which will permit the immediate closing of the valve k^2, as already set forth, thus cutting off the supply of air from the upper chambers.

A cord attached to the ring K^{12} may be carried over pulleys to any convenient point. During the above operations the accumulator not only stores up at the end of each downstroke the air under pressure required for the beginning of the next, but it also provides for all minor inequalities of supply and consumption which take place while the lower chambers are delivering air through the valve I^4. In co-operation with the regulating device shown in Fig. 1, and also in detail, Figs. 10, 11, and 12, as already described, the accumulator not only prevents its own overinflation, but also limits the work of the lower chambers to that required for operative purposes.

The thermal regulator, as already described, varies the working-pressure of the engine as the temperature of the outer atmosphere changes, in accordance with the law that the less the range of temperature through which the air in such an engine passes the greater should be the volume employed and the lower the tension to secure a given power; or, to state the same principle in a different form, the colder the outer atmosphere, and consequently the colder the air delivered by the lower chambers, the greater the range between that minimum and the constant maximum afforded by the steam in the heater and the greater the most effective tension at which that air can be used.

It is obvious that the capacity of the upper and lower chambers should be sufficient to secure the rate of power of the engine under the most unfavorable circumstances—that is, in the warmest weather.

It is obvious that two sets of chambers, &c., could be employed attached to the same beam—one on each side of the fulcrum and post C^3 C^4—the beam in that case being suitably prolonged. As thus arranged the two sets of apparatus would balance each other, and the engine would be double-acting.

It will be observed that all the air supplied to the upper chambers during an operative stroke must pass through both the regenerator, where it is partially heated, and then through the heater, where it is brought to the maximum temperature. During this passage it expands under a constant pressure, so that the volume delivered through the valve k^2 is larger than that supplied through the channel I^7.

As thus constructed and operated the engine is adapted to develop power from atmospheric air or other convenient gas by means of heat of a temperature such as that of the exhaust-steam of a steam-engine or the heat of hot water under the ordinary atmospheric pressure. It will operate successfully at pressures not exceeding two pounds per square inch, and in ordinary use would seldom develop a pressure three times as great. These conditions are all very favorable to the use of flexible cells or chambers, as shown.

It may be observed that the method of employing two sets, each embracing a series of shallow vessels opening and closing simultaneously, renders it practicable to deal with very large volumes of air with much greater ease than would attend the employment of two single cells or chambers having the same aggregate capacity, for, while the practicable limits to the depth and stroke of a single chamber would soon be reached, the method described of employing separate but co-operating chambers of small stroke could be carried out to any desirable extent. The comparatively slow movement of the various parts as secured by the same method is also an important consideration.

It will be observed that the various automatic regulating devices are of a simple character, and that, while having no fine adjustments liable to derangement, they are still adapted under all ordinary circumstances to bring the operation of the engine to a close conformity with established theoretic and practical conditions and requirements.

I do not limit myself to the specific forms and methods described, for it is obvious that my invention might be carried out in various ways.

The method or process of operating the apparatus herein described I have not claimed herein, but have incorporated the method or process and claimed it in my application filed October 18, 1888, Serial No. 288,467.

Having thus described the invention, what I claim as new is—

1. In an air-engine, the combination of a hot-air chamber and a cold-air chamber exposed to the pressure of the outer air and each having flexible walls, a regenerator, and a heating apparatus heated by steam or hot water for the development of power, substantially as set forth.

2. In an air-engine, an operative chamber having flexible walls and arranged and adapted to have a suitable heating medium applied to warm a portion of the internal surface thereof independent of the heat supplied to the air employed therein, substantially as described.

3. In an air-engine, the combination of a series of automatically-movable plates and a series of hot-air chambers having flexible walls and flexible necks or outlets, said plates being arranged and adapted by their simultaneous action to transmit power from said chambers to the working parts of said engine, substantially as and for the purposes set forth.

4. In an air-engine, an accumulator, in combination with a hot-air chamber and arranged and adapted to maintain a uniform pressure in said hot-air chamber during the whole time the hot air is entering therein, as set forth.

5. In an air-engine, an accumulator arranged and adapted to supply heated air to the hot chamber or chambers at the beginning of each inflation thereof before the cold-air chambers commence the delivery of their air, substantially as described.

6. In an air-engine, in combination, an accumulator, a spring, and an intermediate cam or equivalent graduating apparatus, said cam being arranged and adapted to change the varying strain of the spring into a practically uniform pressure on the accumulator, as set forth.

7. In an air-engine, in combination, an accumulator having flexible walls and a spring arranged and adapted to maintain a constant strain upon the movable head of said accumulator, as described.

8. In an air-engine, in combination, an accumulator having flexible walls and a cold-air chamber, said accumulator being arranged and adapted to receive cold air from the cold-air chamber and to supply said air under tension to the hot-air chamber, as set forth.

9. In an air-engine, an accumulator, in combination with a hot-air chamber, and adapted, as described, to maintain a uniform tension in said chamber during nearly the whole of the operative stroke of the engine, substantially as set forth.

10. In an air-engine, an accumulator, in combination with a regenerator, and adapted to transmit air through said regenerator into the hot-air chamber of said engine, substantially as set forth.

11. In an air-engine, in combination, an accumulator, a regenerator, a heater, and means, as described, for supplying said accumulator with cold air under pressure, as and for the purposes set forth.

12. In an air-engine, in combination, an accumulator, a hot-air chamber, and a governor, substantially as and for the purposes set forth.

13. In an air-engine, the combination of hot and cold air chambers having flexible walls and an accumulator, substantially as set forth.

14. In an air-engine, in combination, a cold-air pump and an automatic regulating device arranged to adapt the quantity of air delivered by said pump to that required by the engine, substantially as set forth.

15. In an air-engine, in combination, a cold-air chamber or pump and an automatic regulating device adapted to regulate the amount of air delivered by said pump by controlling the action of the inlet-valve of the said pump or chamber, substantially as and for the purposes set forth.

16. In an air-engine, in combination with a hot-air chamber, a relief-valve opening inwardly and arranged and adapted to admit warm air to the said hot-air chamber when a partial vacuum is formed therein, substantially as set forth.

17. In an air-engine, the combination of hot and cold air chambers having flexible walls, an accumulator, and a thermal apparatus, the whole constructed and operated substantially as and for the purposes set forth.

18. In an air-engine, in combination, a thermal apparatus, an accumulator, and a hot-air chamber or chambers, said thermal apparatus being arranged and adapted to control the tension of the air employed in said hot-air chamber or chambers by the action of the temperature of the external atmosphere, as set forth.

19. In an air-engine, a thermal apparatus actuated by the temperature of the external atmosphere, and a hot-air chamber or chambers, said thermal apparatus being adapted and arranged, as described, to cause an increase of the pressure of the air supplied to said hot-air chamber or chambers by the decrease of the temperature of said atmosphere, substantially as set forth.

20. In an air-engine, in combination with a hot-air chamber or chambers thereof, a thermal apparatus actuated by the temperature of the external atmosphere, and arranged and adapted, as described, to cause a decrease in the pressure of the air supplied to the hot-air chamber or chambers by the increase of the temperature of the atmosphere, substantially as set forth.

21. In an air-engine, the combination of a series of parallel movable plates connected by suitable rods or bars, a corresponding series of fixed parallel plates, and a series of cells or chambers having flexible walls inter-

posed between said series of plates for receiving heated air under pressure, substantially as described, and for the purposes set forth.

22. In an air-engine, the combination of a series of parallel movable plates, a corresponding series of fixed plates, said fixed and movable plates being also adjustable in their relation to each other, and a series of cells or chambers interposed between said series of plates and having flexible walls for receiving cold air, substantially as and for the purposes set forth.

23. In an air-engine, the combination of the fixed plates F and F′, movable plates G and G′, chambers H and H′, heater J, and regenerator J′, constructed and operated substantially as described.

24. In an air-engine employing the heat of hot water or steam, the combination of a hot-air chamber, a cold-air chamber, each having flexible walls and exposed to the pressure of the outer atmosphere, and a valve adapted to cut off communication between said chambers, substantially as and for the purposes set forth.

25. In an air-engine employing the heat of steam or hot water, the combination of a series of hot-air chambers, a series of cold-air chambers, each having flexible walls and each exposed to the pressure of the outer air, a corresponding series of fixed and movable plates, a heater, and a regenerator, substantially as described, and for the purposes set forth.

26. In an air-engine employing the heat of steam or hot water, the combination of a series of hot-air chambers, a series of cold-air chambers, each having flexible walls, fixed and movable plates, as described, and a valve adapted to automatically cut off the supply of air under pressure from the hot-air chambers before their inflation is complete, substantially as described.

In testimony that I claim the foregoing I have hereunto set my hand this 17th day of May, 1888.

JAMES S. BALDWIN.

Witnesses:
O. DRAKE,
E. L. SHERMAN.