(No Model.) 4 Sheets—Sheet 1.

J. A. WOODBURY, J. MERRILL, G. PATTEN & E. F. WOODBURY.

AIR ENGINE.

No. 404,237. Patented May 28, 1889.

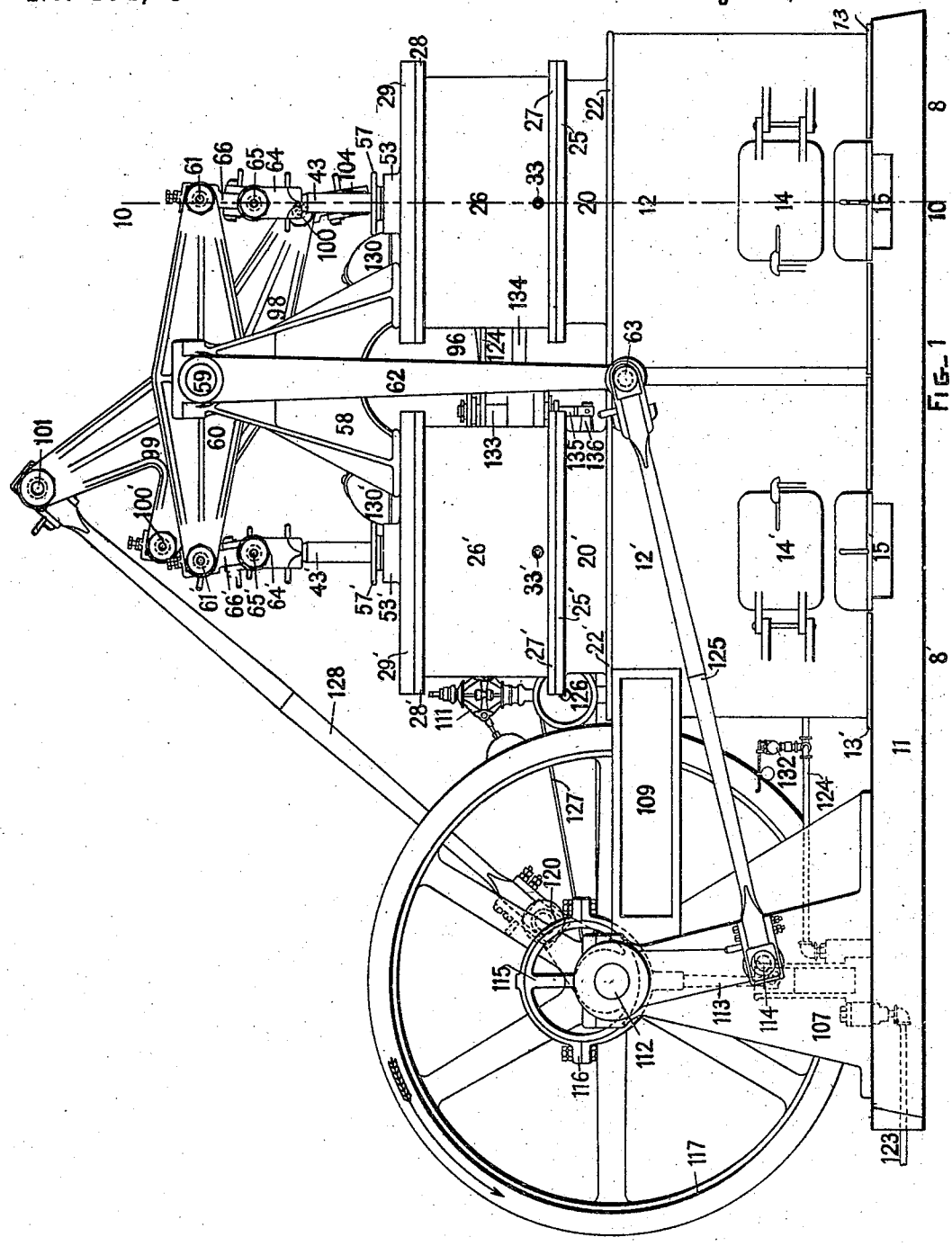

FIG. 1

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No Model.)

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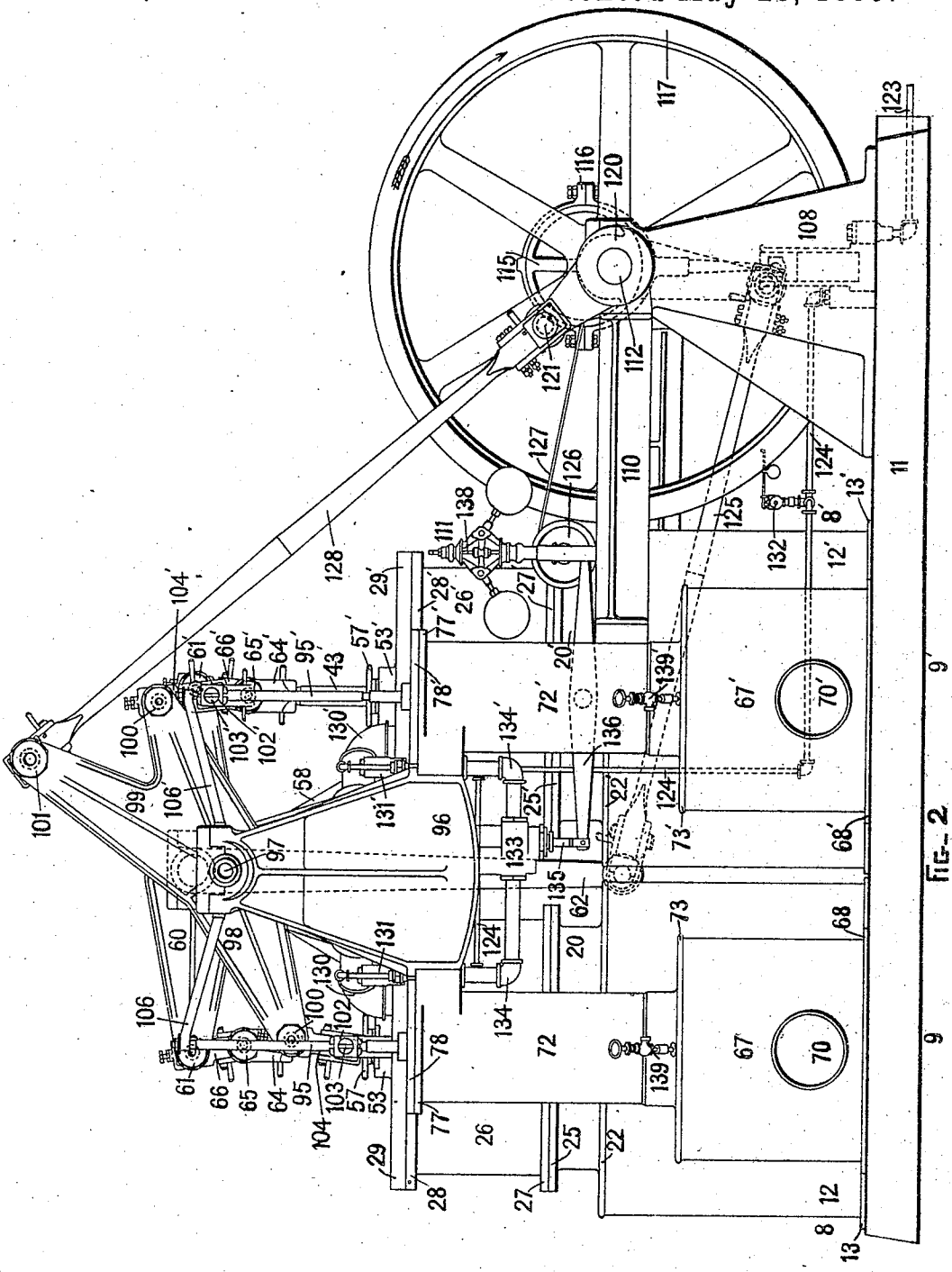

FIG. 2

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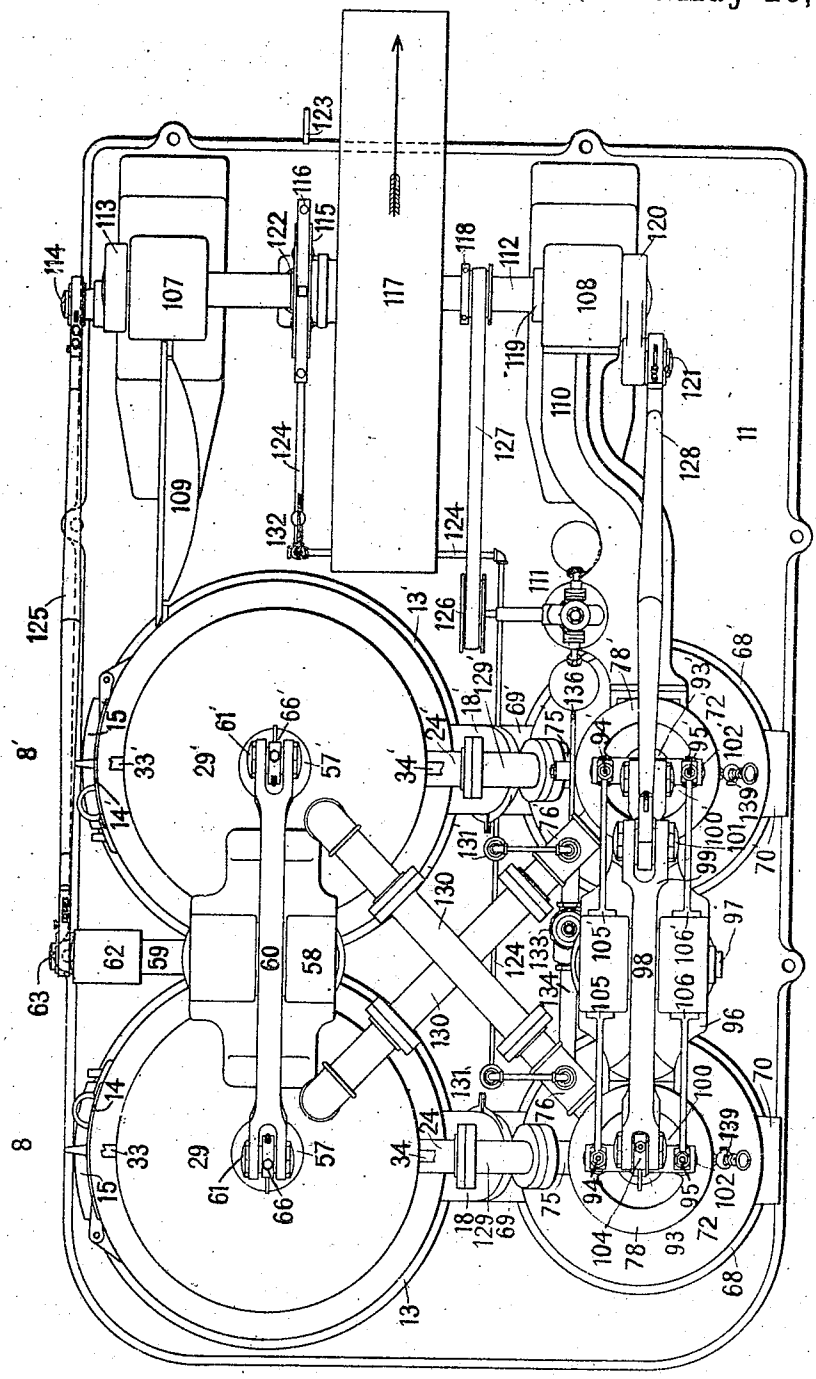

FIG. 3

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No. 404,237. Patented May 28, 1889.

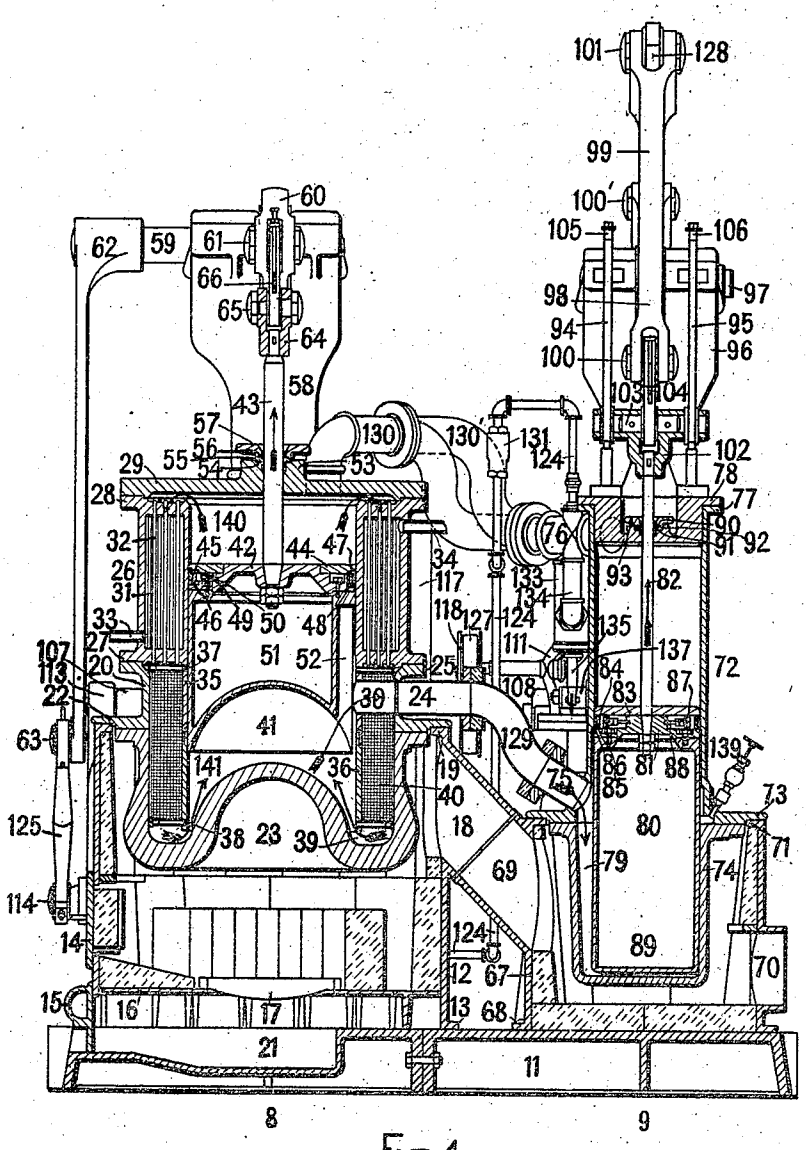

Fig. 4

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UNITED STATES PATENT OFFICE.

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AIR-ENGINE.

SPECIFICATION forming part of Letters Patent No. 404,237, dated May 28, 1889.

Application filed October 5, 1888. Serial No. 287,322. (No model.)

To all whom it may concern:

Be it known that we, JAMES A. WOODBURY, residing at Winchester, in the county of Middlesex and State of Massachusetts, and JOSHUA MERRILL, GEORGE PATTEN, and EDWARD F. WOODBURY, residing at Boston, in the county of Suffolk and State of Massachusetts, citizens of the United States, have invented a new and useful Air-Engine, of which the following is a specification.

Our invention relates to that class of air-engines in which the energy exerted is due to the alternate rising and lowering of temperature of the same mass of air, and it has for its object a perfected air-engine of this class.

Figure 1 represents the air-engine in front elevation. Fig. 2 represents the air-engine in rear elevation. Fig. 3 represents the air-engine in plan, and Fig. 4 is a central vertical sectional view of the same on line 10 10 of Fig. 1.

The essential features of our air-engine are a heater, regenerator, and cooler, which three in combination are termed a "reverser," and in conjunction with a working-cylinder constitute a single-acting air-engine. The drawings represent a double-acting air-engine with two reversers and two working-cylinders. The bed-plate 11, made in halves for convenience, is designed to receive all the parts of the engine, which are superimposed thereon.

The reverser side 8 is constructed as follows: The reverser-furnace 12, which is lined with fire-brick to lessen radiation, is provided with the flange 13, by means of which the furnace is bolted to the bed-plate, door 14, ash-door 15, grate-supporter 16, grate 17, nozzle 18, and flange 19, by means of which the regenerator-cylinder 20 is bolted to the furnace. Underneath the grate is the ash-pit 21.

The regenerator-cylinder 20 is provided with the flange 22, by which the cylinder is bolted to the reverser-furnace and to which the reverser-heater 23 is bolted, pipe 24, and flange 25, to which is bolted the cooler 26.

The cooler 26 is provided with the flange 27, by which it is bolted to the regenerator-cylinder, flange 28, to which is bolted the cooler-cover 29, air-directing pipe 30, and annular tube and water-space 31, through which extend the copper cooling-tubes 32, which are securely expanded into the tube-holes in the flanges 27 and 28. The annular space is provided with the water-inlet pipe 33 and the water-outlet pipe 34. To the displacer-cylinder portion 35 of the cooler is fastened the displacer-cylinder 36. To the upper part of the displacer-cylinder portion of the cooler a row of regenerator-pins, as 37, is fastened, and to the lower portion of the displacer-cylinder a row of regenerator-pins, as 38, is fastened. The space between the displacer-cylinder portion and displacer-cylinder and the regenerator-cylinder and reverser-heater is termed the "regenerator-space" 39. Within this space is placed the regenerator 40, which is made, preferably, of yellow high brass-wire cloth; size of wire, about No. 25, Stubbs' wire-gage, and about No. 12 mesh. This wire is wound on and around the displacer-cylinder portion 35 and displacer-cylinder 36 between the rows of regenerator-pins, as 37 and 38, until a continuous roll is formed of a thickness sufficient to fill or nearly fill the regenerator-space. Then the end of the roll is fastened, so as to prevent its unwinding.

The reverser-piston 41 is provided with the piston-head 42, piston-rod 43, follower 44, and a style of packing commonly known as the "two-ring" packing, composed of the two packing-rings 45 and 46, placed between the composition seats 47 and 48 of the piston-head and follower, respectively. The rings are set out radially by a series of leaf-springs, as 49, and setting-out bolts, as 50, in the usual manner. To the reverser piston-head is bolted the reverser-piston lower section, 51, which is provided with the air-port 52.

The cooler-cover 29, which is bolted to the cooler, is provided with the nozzle 53, designed to receive the two leather-cupped packings 54 and 55 for the reverser-piston rod, relief packing-ring 56, and gland 57.

The reverser side 8′ is a duplicate of the reverser side 8, and in a like manner is provided with the reverser-furnace 12′, having flange 13′, door 14′, ash-door 15′, regenerator-cylinder 20′, having pipe 24′ and flanges 22′ and 25′, cooler 26′, having flanges 27′ and 28′, water-inlet pipe 33′ and water-outlet pipe 34′

and cooler-cover 29′, having nozzle 53′ and gland 57′, through which extends the reverser-piston rod 43′.

To the cooler-covers 29 and 29′ is bolted the reverser-beam stand 58, in which is mounted the trunnion 59. To the trunnion is fastened the reverser-beam 60, provided with the reverser-beam pins 61 and 61′ and side lever, 62, provided with pin 63.

To the reverser-piston rod 43 is keyed the cross-head 64, which is provided with the cross-head pin 65. The cross-head pin 65 and reverser-beam pin 61 are connected by means of the connecting-link 66. In a like manner to the reverser-piston rod 43′ is keyed the cross-head 64′, which is provided with the cross-head pin 65′. The cross-head pin 65′ and reverser-beam pin 61′ are connected by means of the connecting-link 66′.

The working-cylinder furnace 67, which is lined with fire-brick to lessen radiation, is provided with the flange 68, by means of which the furnace is bolted to the bed-plate, nozzle 69, nozzle 70, and flange 71, by means of which the working-cylinder 72 is bolted to the furnace. The working-cylinder 72 is provided with the flange 73, by which the cylinder is bolted to the working-cylinder furnace, and to which is bolted the working-cylinder heater 74, pipe 75, pipe 76, and flange 77, to which is bolted the working-cylinder head 78. The working-cylinder heater 74 is provided with the side air-port, 79. The working-cylinder piston 80 is provided with the piston-head 81, piston-rod 82, follower 83, and a style of packing commonly known as the "three-ring" packing, composed of the three packing-rings 84, 85, and 86, placed between the piston-head and follower. The rings are set out radially by a series of leaf-springs, as 87, and setting-out bolts, as 88, in the usual manner. To the working-cylinder piston-head is bolted the working-cylinder piston lower section, 89.

The working-cylinder head 78, which is bolted to the working-cylinder, is provided with the two leather-cupped packings 90 and 91 for the working-cylinder piston-rod, relief packing-ring 92, and gland 93, and the two cross-head guides 94 and 95, which are securely bolted to the working-cylinder head. The working-cylinder side 9′ is a duplicate of the working-cylinder side 9, and in a like manner is provided with the working-cylinder furnace 67′, having flange 68′, nozzle 69′, and nozzle 70′, working-cylinder 72′, having flange 73′, pipe 75′, pipe 76′, and flange 77′, and working-cylinder head 78′, provided with cross-head guides 94′ and 95′, through which cylinder-head extends the working-cylinder piston-rod 82′.

To the working-cylinders 72 and 72′ is bolted the working-cylinder beam-stand 96, in which is mounted the trunnion 97. To the trunnion is fastened the working-cylinder beam 98, provided with the horn 99 and the beam-pins 100, 100′, and 101.

To the working-cylinder piston-rod 82 is keyed the cross-head 102, adapted to slide on and to be guided by the cross-head guides 94 and 95 and provided with the cross head pin 103. The cross-head pin 103 and the working-cylinder beam-pin 100 are connected by means of the connecting-link 104. In a like manner to the working-cylinder piston-rod 82′ is keyed the cross-head 102′, provided with the cross-head pin 103′. The cross-head pin 103′ and working-cylinder beam-pin 100′ are connected by means of the connecting-link 104′.

The cross-head guides 94 and 95 are braced by means of the cross-head guide-braces 105 and 106, respectively. In a like manner the cross-head guides 94′ and 95′ are braced by means of the cross-head guide-braces 105′ and 106′, respectively.

To the bed-plate the pillow-blocks 107 and 108 are bolted. The pillow-block 107 is braced by means of the reverser-furnace brace 109. The pillow-block 108 is braced by means of the working-cylinder brace 110, to which is bolted the centrifugal governor 111, of a common style. Within the pillow-blocks the main shaft 112 is journaled, which is provided with reverser-crank 113, having reverser-crank pin 114, air-pump eccentric 115, having eccentric-straps 116, fly-wheel 117, governor-pulley 118, thrust-collar 119, and working-cylinder crank 120, having working-cylinder crank-pin 121. The air-pump 122, bolted to bed-plate, is of the single-acting piston type, and is operated in the usual manner by means of air-pump eccentric 115. It is provided with the air-inlet pipe 123 and the air-outlet pipe 124. The reverser-beam side lever-pin, 63, is connected with the reverser crank-pin 114 by means of reverser connecting-rod 125. The pulley 126 of the governor is connected with governor-pulley 118 by means of belt 127.

The pin 101 of the horn 99 of the working-cylinder beam is connected with working-cylinder crank-pin 121 by means of working-cylinder connecting-rod 128. The reverser side 8 is connected with the bottom of working-cylinder 72 by means of pipe 24, pipe 75, and lower connecting-pipe, 129, and flanges. In a like manner the reverser side 8′ is connected with the bottom of working-cylinder 72′ by means of pipe 24′, pipe 75′, and lower connecting-pipe, 129′, and flanges. The top of working-cylinder 72′ is connected with reverser side 8 by means of pipe 76′ and upper connecting-pipe, 130, and flanges, which upper connecting-pipe extends through the cooler-cover 29. In a like manner the top of working-cylinder 72 is connected with reverser side 8′ by means of pipe 76 and upper connecting-pipe, 130′, and flanges, which upper connecting-pipe extends through the cooler-cover 29′.

To the pipe 76 is connected the check-valve 131, which is of a common style and is designed to operate in the usual manner. In a like manner to the pipe 76′ is connected the check-valve 131′. The check-valves 131 and

131′ are connected with the air-pump by means of the air-pump outlet-pipe 124. The safety-valve 132, of a well-known style, is connected with the air-pump outlet-pipe 124. The governor-valve 133 is connected on one side by means of piping 134 with pipe 76 and on the other side by means of piping 134′ with pipe 76′. The governor-valve is of the reciprocating type, and is provided with the stem 135, which is connected with one end of the governor-lever 136, a lever of the first class, pivoted at 137. The other end of the governor-lever is connected with the spindle 138 of the governor. The working-cylinders 72 and 72′ are provided with the blow-off valves 139 and 139′, respectively.

In the construction of the reverser side 8 suitable ports are made for the free passage of the air displaced by the displacer-piston from the cool chamber 140 above the displacer-piston, into and through the cooling-tubes, through the regenerator, around the lower portion of displacer-cylinder, and into the hot chamber 141 below the displacer-piston; also from the cool chamber 140, through pipes 130 and 76′, to the top portion of working-cylinder 72′ and into the space above the working-cylinder piston, and from the hot chamber 141, through port 52, pipe 30, pipe 24, pipe 129, and pipe 75, into the lower portion of working-cylinder 72, through port 79, and into the space below the working-cylinder piston 80. In a like manner in reverser side 8′ suitable ports are made for the free passage of the air displaced by the displacer-piston from the cool chamber to the hot chamber and from the cool chamber to the top portion of working-cylinder 72, and into the space above the working-cylinder piston 80, and from the hot chamber to the lower portion of working-cylinder 72′, and into the space below the working-cylinder piston of working-cylinder 72′.

Description of the preliminary steps to be taken prior to the starting of the engine.—It being predetermined to have the engine run over, as indicated by arrow on fly-wheel, the relative positions of the cranks 113 and 120 should be such as will give the reverser-piston of the reverser side 8 a lead over the working-cylinder piston of the working-cylinder side 9 of from one-third to one-half stroke. The lead represented in Fig. 4 is one-half stroke, the direction of movement of the pistons being indicated by arrows in Fig. 4. The reverser-pistons of reverser sides 8 and 8′ being connected by means of the reverser-beam and connecting parts, and the working-cylinder pistons of working-cylinder sides 9 and 9′ being connected by means of working-cylinder beam and connecting parts, it is evident that the reverser-piston of reverser side 8′ will have the same lead over the working-cylinder piston of working-cylinder side 9′ as the reverser-piston of reverser side 8 has over working-cylinder piston of working-cylinder side 9. The water-inlet pipe 33 of cooler 26 is connected with suitable water-supply, and a circulation of water is maintained in the annular tube and water-space 31 and out of the cooler through water-outlet pipe 34, from which the water is conveyed by means of suitable piping to any convenient place. In a like manner a circulation of water is maintained in cooler 26′ through water-inlet pipe 33′ and water-outlet pipe 34′. A fire is then started in both of the reverser-furnaces. In reverser side 8 the fire is started upon the grate 17 within the reverser-furnace 12, and the products of combustion pass about and around the reverser-heater 23 through nozzles 18 and 69 into the working-cylinder furnace 67, then about and around the working-cylinder heater 74, and then escapes through the nozzle 70 into chimney through suitable piping. In a like manner in reverser side 8′ the products of combustion pass from reverser-furnace 12′ to working-cylinder furnace 67′, through nozzles 18′ and 69′, and then escape through the nozzle 70′. When sufficient heat has been imparted to the reverser and working-cylinder heaters, the engine may be set in operation by giving the fly-wheel about a one-half revolution in the direction of its running movement.

In the operation of the engine the alternate raising and lowering of the temperature of the same mass of air is accomplished as follows: In the upward stroke of the reverser-piston 41 the mass of air in the cool chamber 140 is forced, first, through the cooling-tubes in its downward passage, through which the temperature of the air is not materially changed; second, the air enters the regenerator 40, and in its passage through the regenerator it absorbs heat which has been imparted to the regenerator; third, the air then passing over the heated surface of the reverser-heater, thereby becoming further heated, enters the hot chamber 141. The temperature of the air in the cool chamber is about 120° Fahrenheit, and the temperature of the air in the hot chamber is about 600° Fahrenheit. In the downward stroke of the reverser-piston 41 the mass of air in the hot chamber 141 is forced, first, to the regenerator 40; second, the air enters the regenerator, and in its passage through the same it deposits thereon the greater portion of its heat; third, through the cooling-tubes, where its temperature is reduced to about 120° Fahrenheit, and then into the cool chamber 140. Therefore at each upward and downward stroke of the reverser-piston of reverser side 8 the temperature of the same mass of air is alternately raised and lowered, and the reverser side 8′ being a duplicate of reverser side 8, it is evident that the same alternate raising and lowering of the temperature of the air would take place in reverser side 8′ as in reverser side 8, but at opposite times—that is to say, both reverser-pistons being operated by the reverser-beam, whenever one reverser-piston is making its upward stroke the other reverser-

piston is making its downward stroke. It is therefore evident that when the air in one reverser side is being heated the air in the other reverser side is being cooled. The alternate raising and lowering of the temperature of the reversed air in both reverser sides generates a power in accordance with the well-known laws of the expansion of gases, which power is developed by the working-cylinders as follows: Referring to Fig. 4, and presuming the movements of the reverser and working-cylinder pistons to be in the direction as indicated by arrows, the reverser-piston of reverser side 8 is making its upward stroke and is heating and expanding the displaced air, thereby producing a pressure which is exerted against the bottom of working-cylinder piston of working-cylinder side 9 and against the top of working-cylinder piston of working-cylinder side 9′, between which and the reverser side 8 are open ports, while at the same time the reverser-piston of reverser side 8′ is making its downward stroke and is cooling and contracting the displaced air, thereby reducing the pressure against the bottom of working-cylinder piston of working-cylinder side 9′ and the top of working-cylinder piston of working-cylinder side 9, between which and the reverser side 8′ are open ports. Thus each working-cylinder piston is subjected to differential pressures, which are alternately reversed as the displaced air is alternately heated and cooled. Thus a power is exerted to cause the working-cylinder pistons to have reciprocating motion, which is changed to a rotary motion by means of the working-cylinder beam and its connected parts to the main shaft and fly-wheel, from which the power may be taken off by means of a belt. A portion of the power developed is absorbed in the friction of the engine, and a portion is used to operate the reverser-pistons by means of reverser-crank, reverser connecting-rod, side lever, trunnion, reverser-beam, and connected parts.

The engine is designed to run on an initial pressure of air of from four to five atmospheres, and the duty of the air-pump is to supply and maintain this initial pressure of air in the engine, which duty is accomplished as follows: After the starting of the engine at each revolution of the engine a certain quantity of air is pumped by the air-pump into the air-outlet pipe 124, from which the engine receives the compressed air, which passes into reverser side 8 through check-valve 131′, pipes 76′ and 130, and into reverser side 8′ through check-valve 131, pipes 76 and 130′. In practice a reservoir is usually placed for convenience in circuit with the air-outlet pipe 124. The safety-valve 132 is placed on the air-outlet pipe 124 for the purpose of controlling the pressure of the air supplied to the engine. By setting the safety-valve at forty-five pounds from zero, or four atmospheres, it is evident that any air above that pressure will be permitted to escape into the atmosphere through the safety-valve, and as the safety-valve may be set at any number of pounds desired it is obvious that any initial pressure may be maintained in the engine. The air-pump not only supplies the initial pressure, but it supplies any leakage of air that may leak out of the engine around the piston-rods and flange-joints.

The duty of the governor and governor-valve is to equalize the differential pressures in the engine, and, as the differential pressures are the power-producing factors of the engine, therefore, in regulating the difference of the differential pressures, the power, and consequently the speed, of the engine may be regulated. This regulation of the engine is accomplished as follows: The governor being of the ordinary centrifugal style, and being connected with the governor-valve, of a reciprocating type, by means of the lever of the first class, any increase of speed of the engine would raise the governor-balls, thereby depressing the spindle of the governor and raising the stem of the governor-valve, thereby opening the governor-valve, which controls the opening between the two reverser sides of the engine—that is to say, between reverser sides 8 and 8′—and as the size of the opening between the two reverser sides of the engine is controlled by the action of the governor in opening and closing the governor-valve the difference of the differential pressures is consequently controlled, and therefore the power and speed of the engine are regulated.

It has been determined by us after many years of costly scientific and practical experimenting that the following special construction and arrangement are of vital importance: The cold chamber should be directly connected with the top of a working-cylinder and the hot chamber should be directly connected with the bottom of a working-cylinder; the regenerator should occupy the regenerator-space between the regenerator-cylinder, reverser-heater, and displacer-cylinder, and should extend from the cooler to a point at or near the bottom of the reverser-heater; the regenerator should be composed of wire-cloth and located in the regenerator-space, as stated; the cooler should have a cast annular tube and water-space; the cooler should be provided with a cooler-cover, as represented and described, which should be provided with a connecting-pipe to a working-cylinder; the cooler should have a cast annular tube and water-space, through which should pass the cooling-tubes; the cooler should have cast thereon a displacer-cylinder portion; the displacer-cylinder should be securely fastened to the displacer-cylinder portion of the cooler; the regenerator should be composed of wire-cloth and should be wound onto the displacer-cylinder portion and displacer-cylinder; the regenerator composed of wire-cloth and wound onto displacer-cylinder portion and displacer-cylinder should be held in po-

sition vertically between rows of regenerator-pins.

What we claim as our invention, and desire to secure by Letters Patent, is—

1. An air-engine in which the temperature of the same mass of air is alternately raised and lowered, having a reverser provided with a hot and cold chamber, each of which is directly connected with a working-cylinder, substantially as and for the purpose set forth.

2. In an air-engine in which the temperature of the same mass of air is alternately raised and lowered, the reverser side, as 8, provided with the regenerator-space formed between the regenerator-cylinder, reverser-heater, and displacer-cylinder, within which is placed the regenerator, in combination with the tubular cooler having the cooling-tubes and provided with the cooler-cover, substantially as described.

3. In an air-engine in which the temperature of the same mass of air is alternately raised and lowered, having the reverser side, as 8, the combination, with the tubular cooler having the cooling-tubes and provided with the cooler-cover, of the regenerator composed of wire-cloth and placed within an annularly-constructed space at or near the inner surface of the outer shell of the heater, substantially as and for the purpose set forth.

4. In an air-engine, the combination, with reverser-heater provided with an annular regenerator-space at or near the inner surface of its outer shell, of the cooler provided with the annular tube and water-space, having the cooling-tubes and provided with the cooler-cover, substantially as described.

5. In an air-engine, the combination of the reverser-heater, a wire-cloth regenerator, the tubular cooler, and cooler-cover provided with the connecting-pipe by means of which the cold chamber is directly connected with a working-cylinder, substantially as and for the purpose set forth.

6. In an air-engine, the combination, with the reverser-heater, of the cooler provided with the annular tube and water-space and cooler-cover and having the cooling-tubes, and the cold chamber within which the displacer-piston reciprocates, substantially as described.

7. In an air-engine having a reverser-side, as 8, the tubular cooler having the cooling-tubes and provided with the cooler-cover, within which cooler the displacer-piston reciprocates, provided with the displacer-cylinder portion cast on said cooler, said portion being adapted to receive within it the displacer-piston, substantially as described.

8. In an air-engine having a reverser side, as 8, the tubular cooler having the cooling-tubes and provided with the cooler-cover, within which cooler the displacer-piston reciprocates, provided with the displacer-cylinder portion, in combination with displacer-cylinder (adapted to receive within it the displacer-piston) fastened to said displacer-cylinder portion, substantially as and for the purpose set forth.

9. In an air-engine having a reverser side, as 8, the combination, with the cooler having the cooling-tubes and provided with the displacer-cylinder and cooler-cover, of the regenerator wound on said displacer-cylinder, composed of wire-cloth, substantially as described.

10. In an air-engine having a reverser side, as 8, the cooler provided with displacer-cylinder, which is provided with a series of regenerator-pins, as 37 and 38, in combination with the regenerator composed of wire-cloth and wound on said displacer-cylinder and between said series of regenerator-pins, substantially as described.

11. An air-engine in which the temperature of the same mass of air is alternately raised and lowered, having the reversers, each of which is provided with a hot and cold chamber when each of said chambers is directly connected with the working-cylinders, substantially as described.

12. In an air-engine in which the temperature of the same mass of air is alternately raised and lowered, the combination of two reversers and two double-acting working-cylinders with a regenerator composed of wire-cloth, said cylinders being directly connected by means of connecting-pipes, as shown, substantially as described.

13. In an air-engine in which the temperature of the same mass of air is alternately raised and lowered, having a reverser provided with a hot and cold chamber, each of which is directly connected with a double-acting working-cylinder, in combination with a regenerator, substantially as described.

14. In an air-engine in which the temperature of the same mass of air is alternately raised and lowered, having a reverser provided with a heater, regenerator-cylinder, a wire-cloth regenerator, and a tubular cooler having the cooling-tubes and provided with the cooler-cover, so constructed and arranged as to provide for an annular port having straight or nearly straight sides and extending from the cooler to the bottom of the heater, so that the air may have a direct and a free passage to and from the hot and cold chambers, substantially as described.

In testimony whereof we have signed our names to this specification in the presence of two subscribing witnesses.

JAMES A. WOODBURY.
JOSHUA MERRILL.
GEORGE PATTEN.
EDWARD F. WOODBURY.

Witnesses:
WALTER L. PERRY,
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