No. 708,027. Patented Sept. 2, 1902.

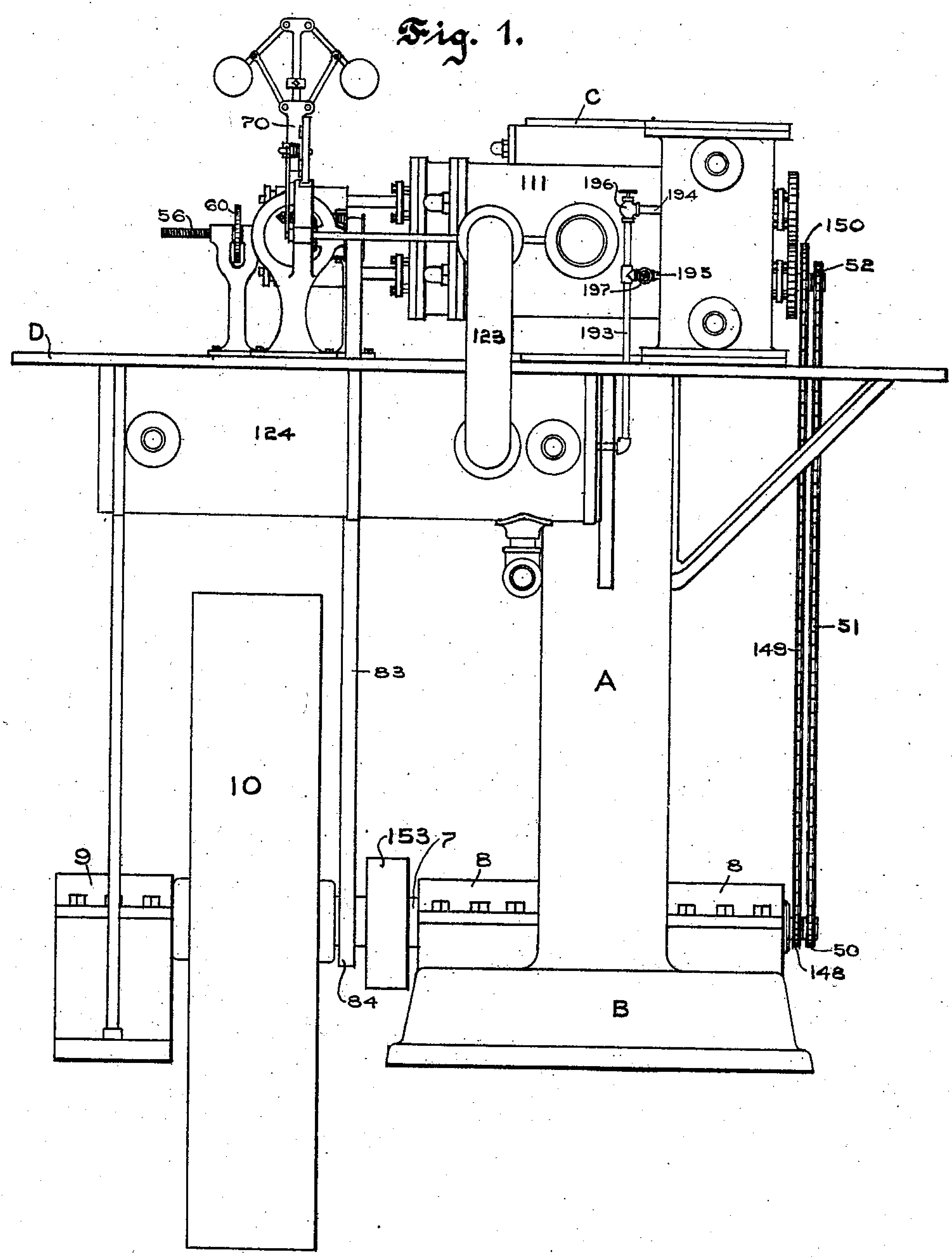
S. J. CORRIGAN.

AERO-STEAM ENGINE.

(Application filed Sept. 3, 1901.)

(No Model.) 9 Sheets—Sheet 1.

Fig. 1.



Witnesses,
W. H. Palmer.
Emily Eastman

Inventor,
Severinus J. Corrigan.
by Lothrop & Johnson
his Attorneys.

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

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9 Sheets—Sheet 2.

Fig. 2.

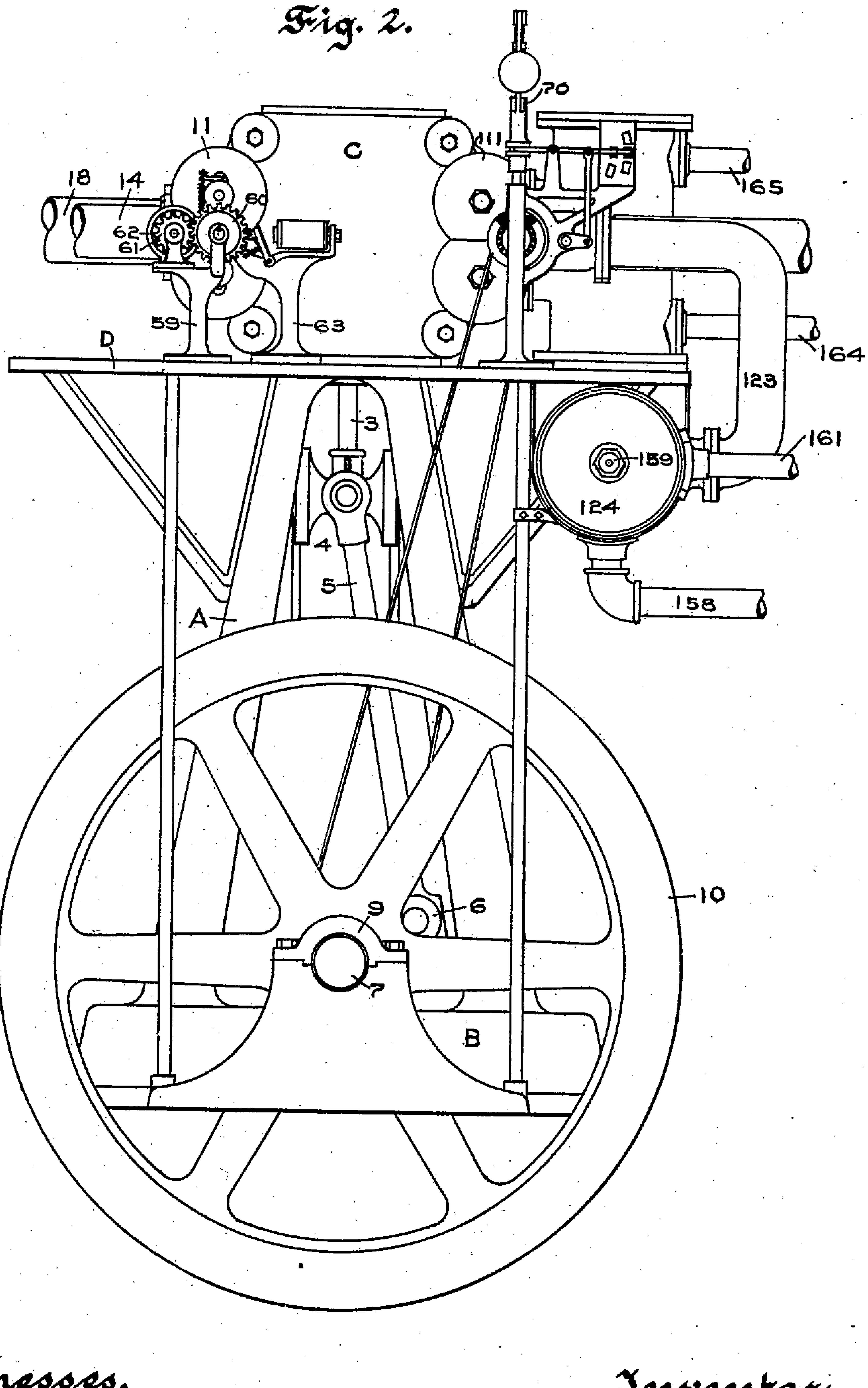

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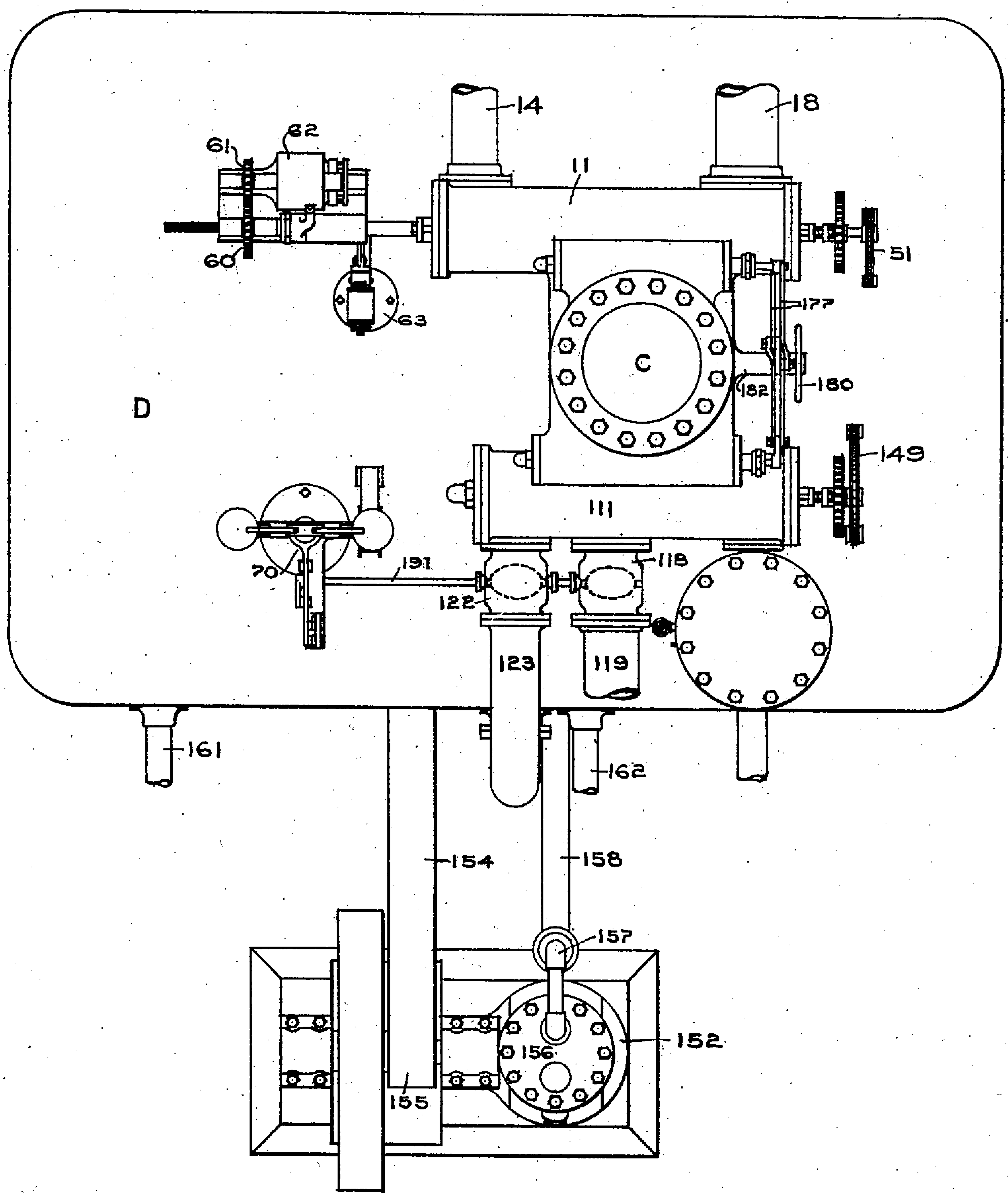
Fig. 3.



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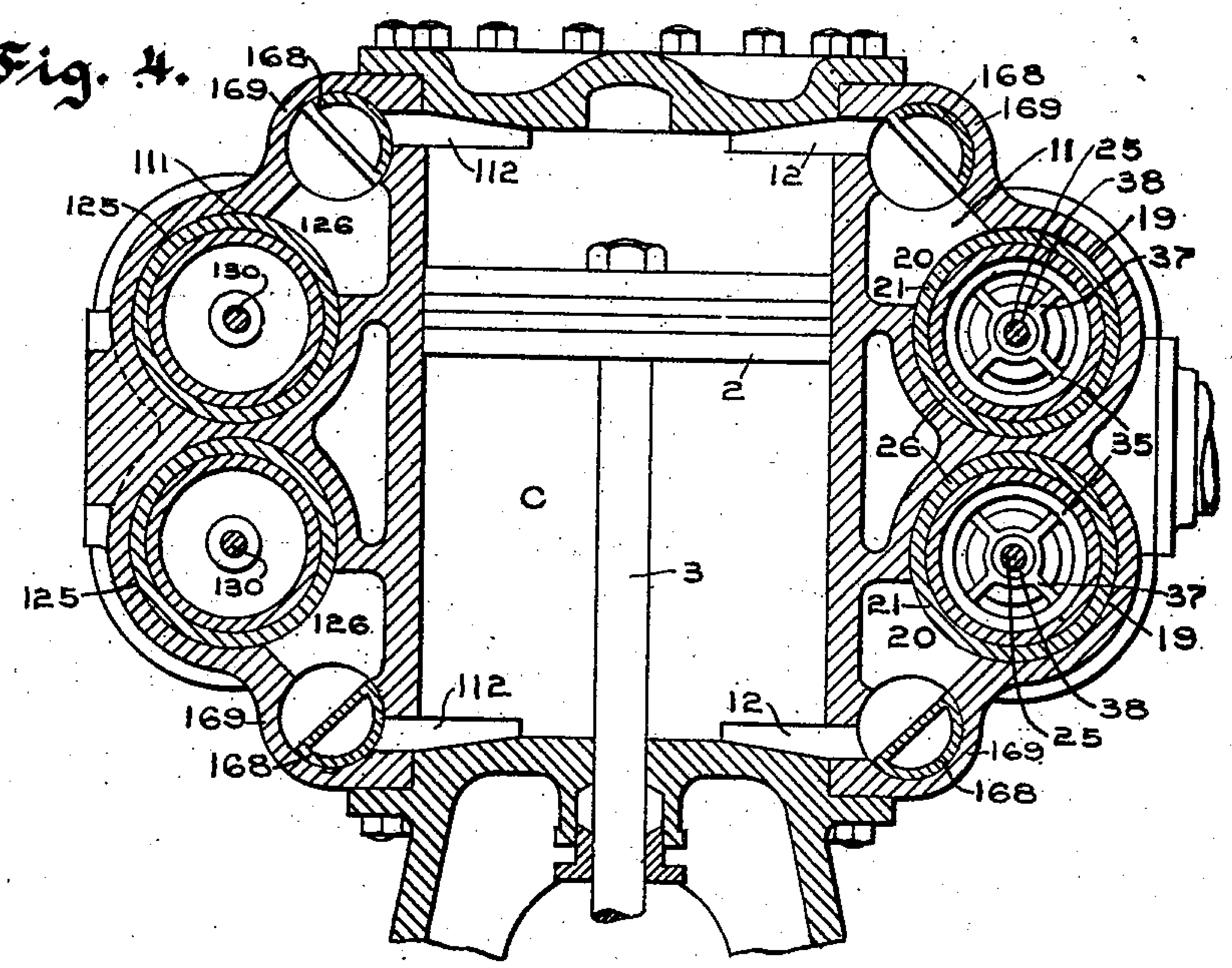
9 Sheets—Sheet 4.

Fig. 4.



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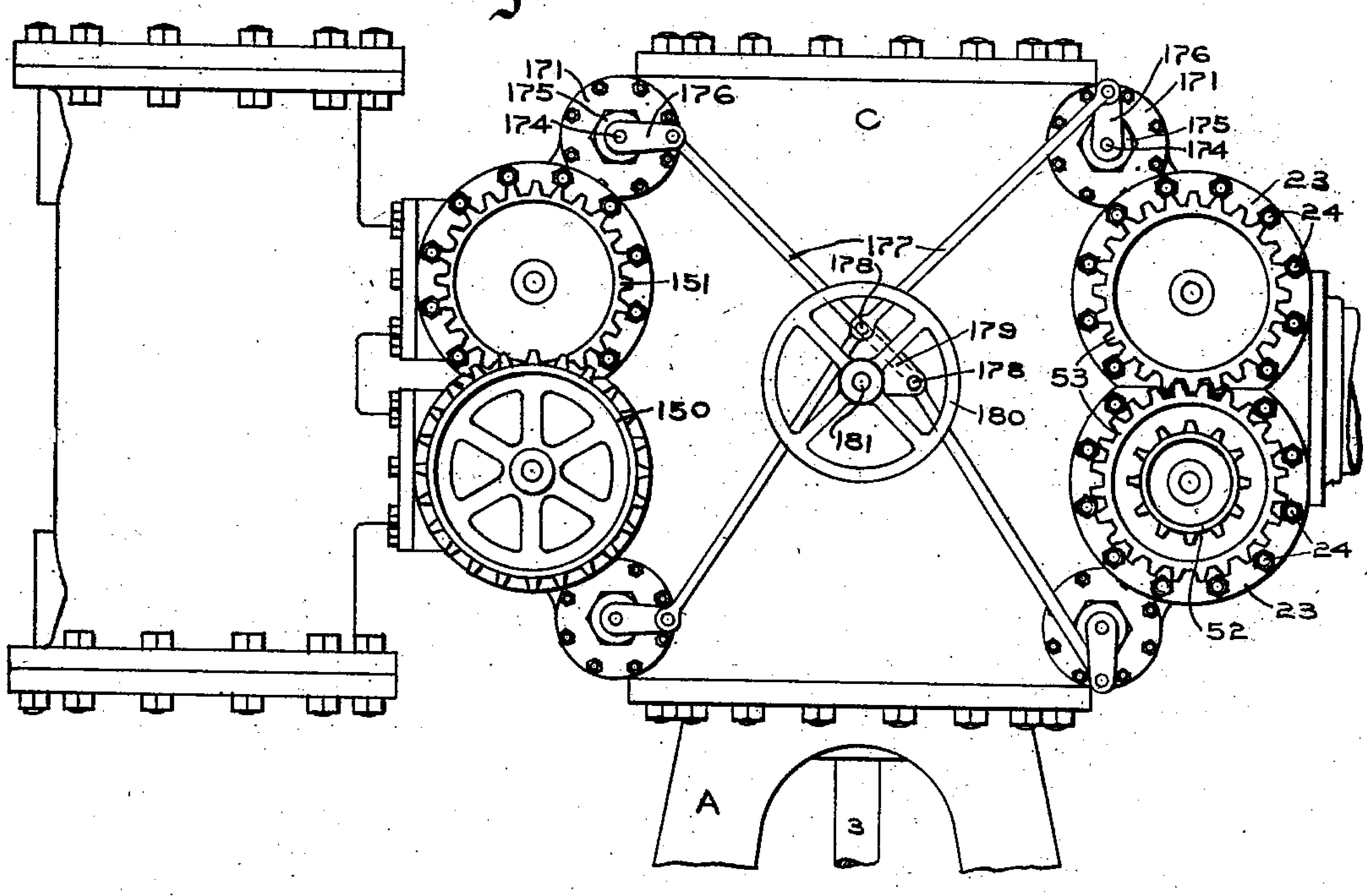

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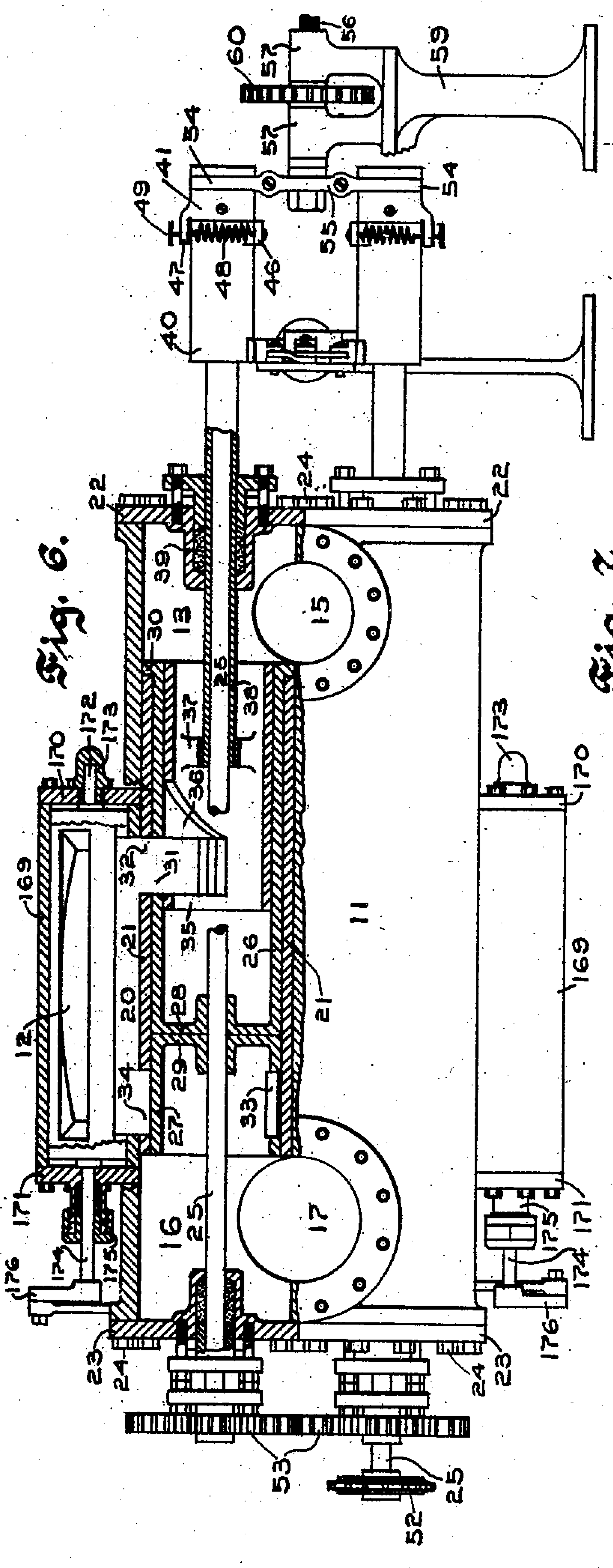
(No Model.) 9 Sheets—Sheet 5.



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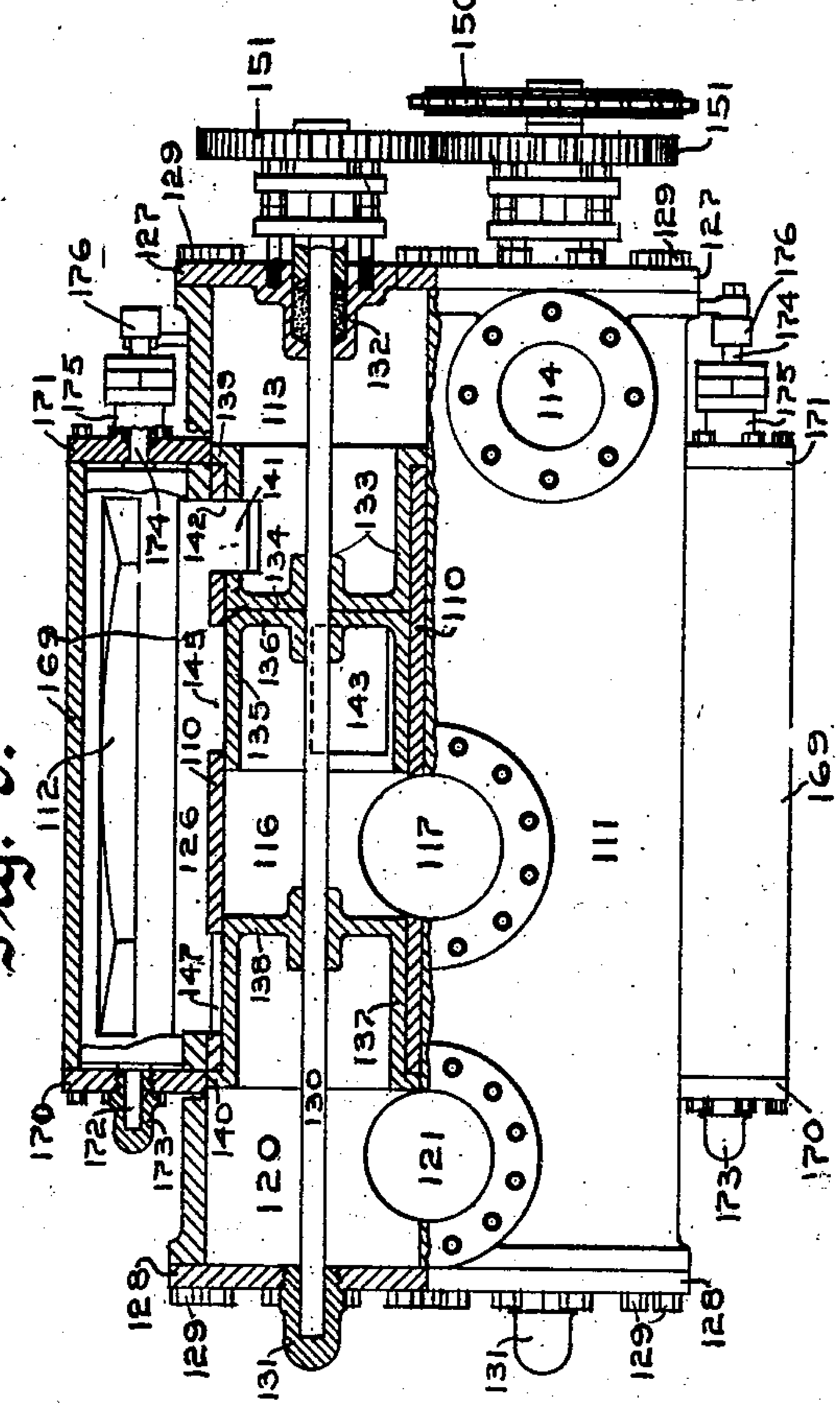

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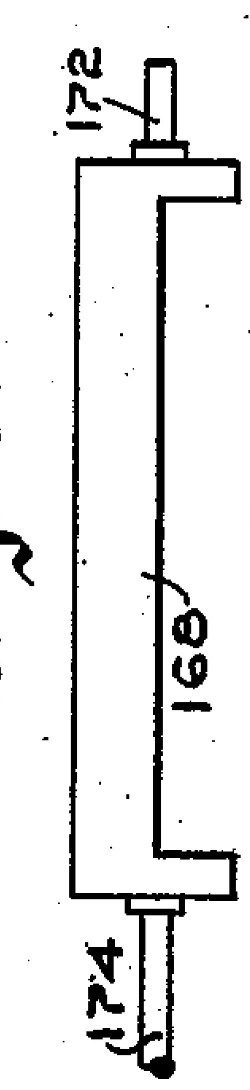

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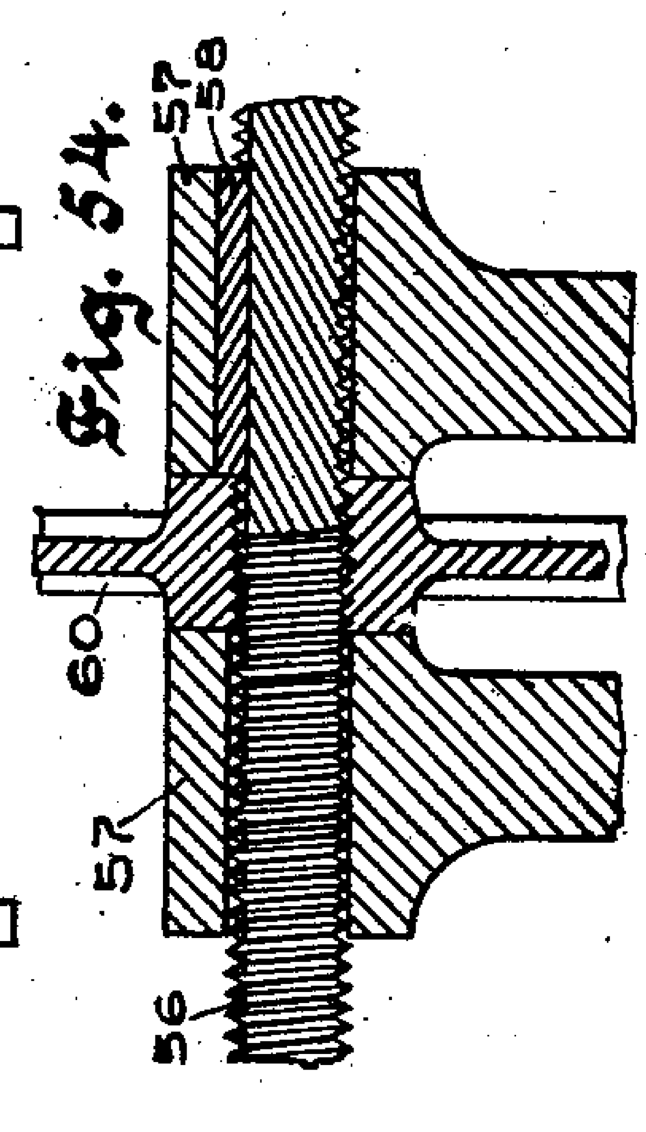

Fig. 54.

Witnesses,
W. H. Palmer
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Inventor,
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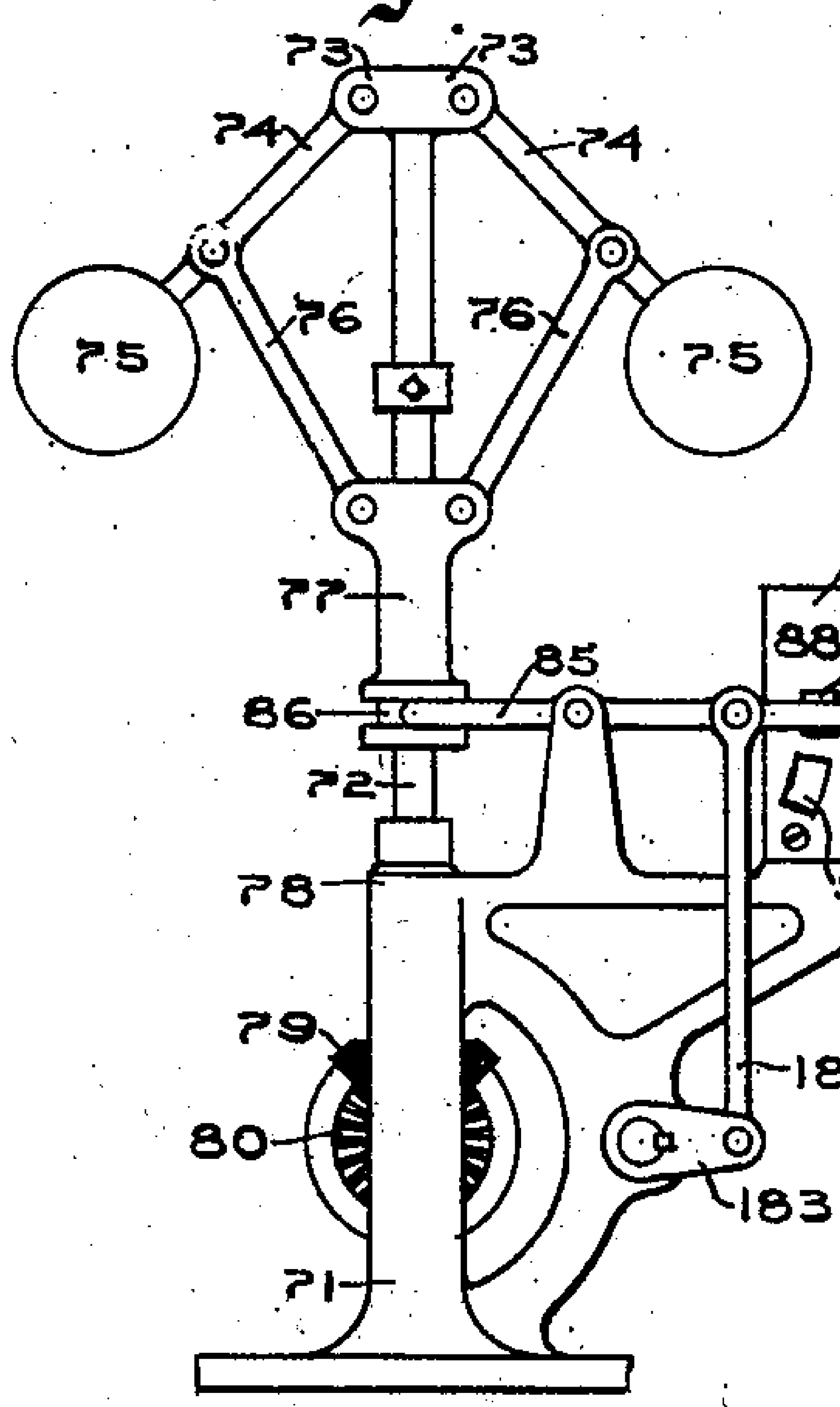
Fig. 9.



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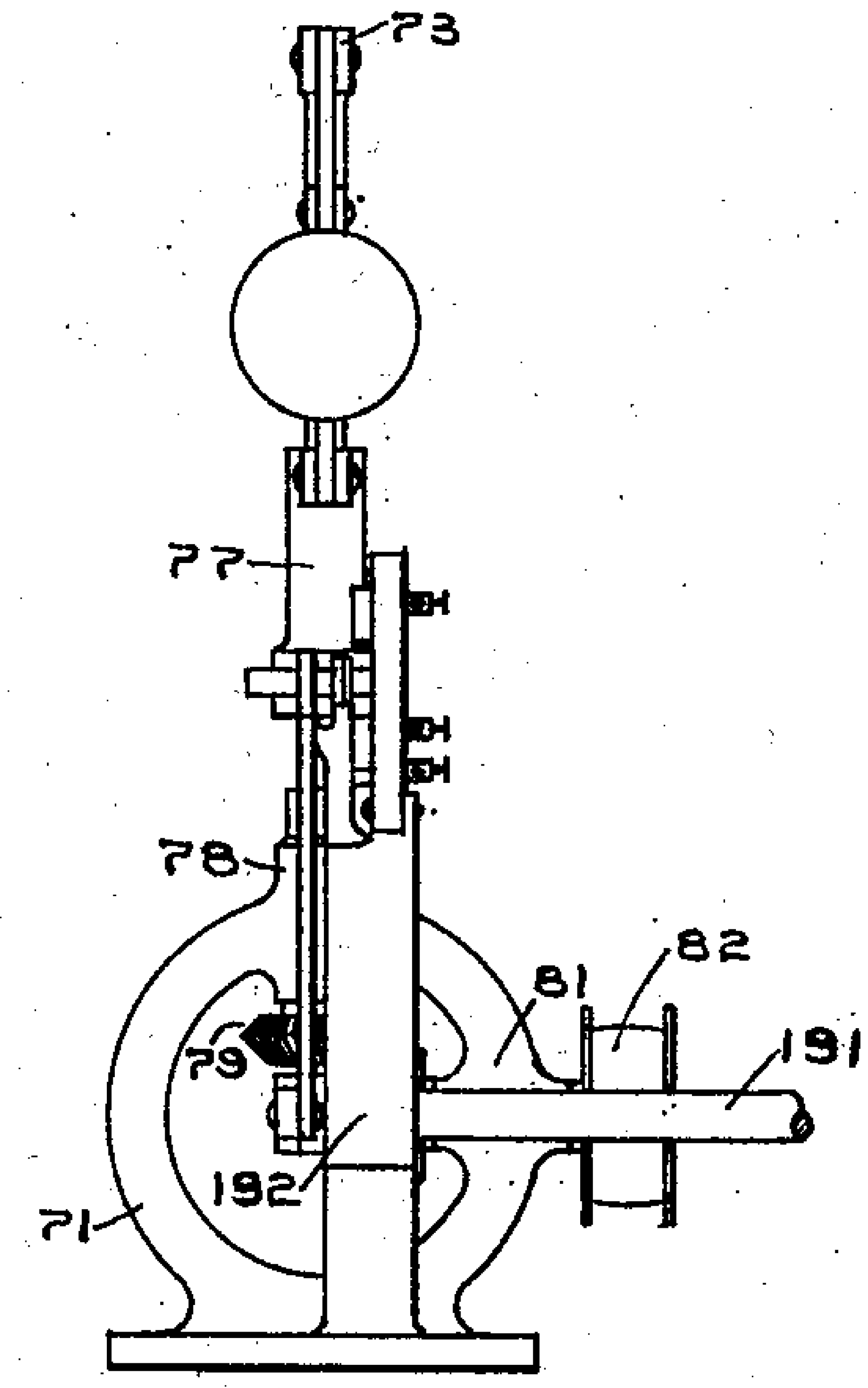

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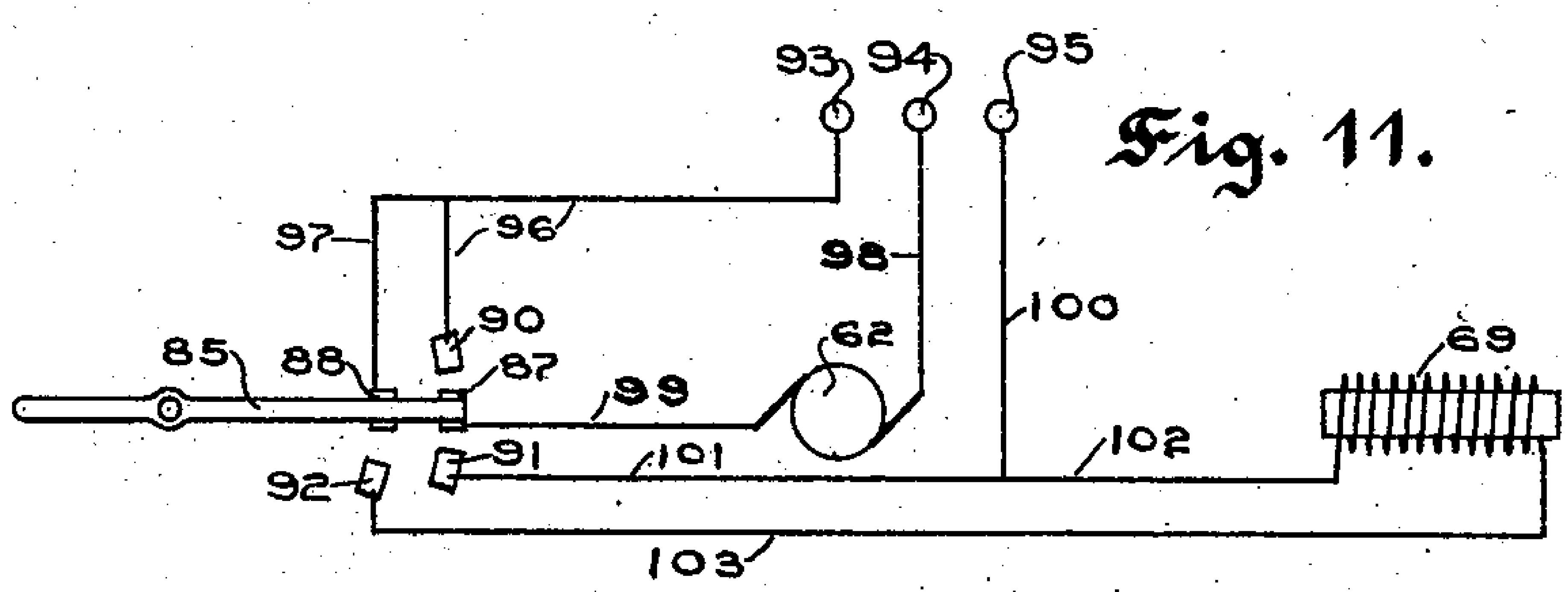

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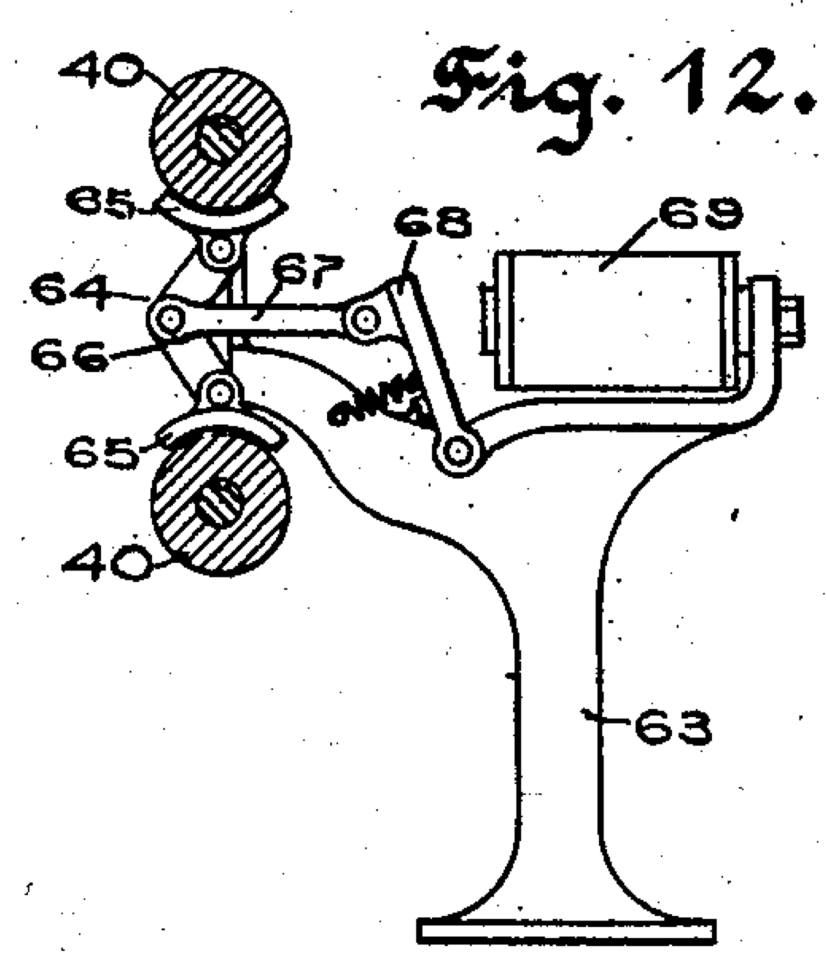

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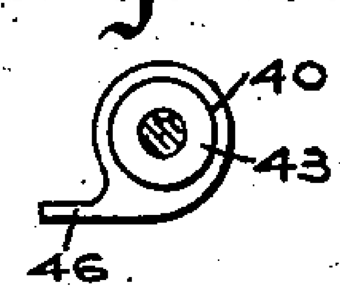

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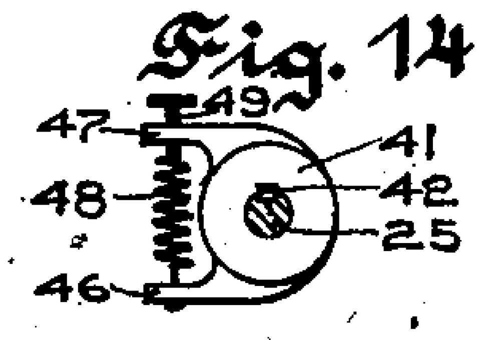

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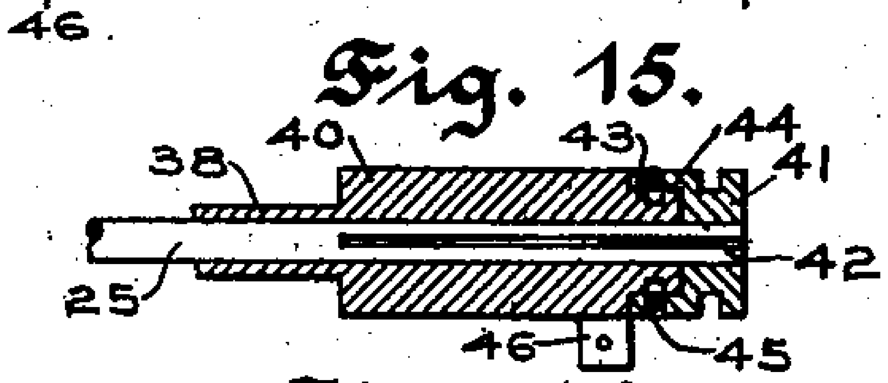

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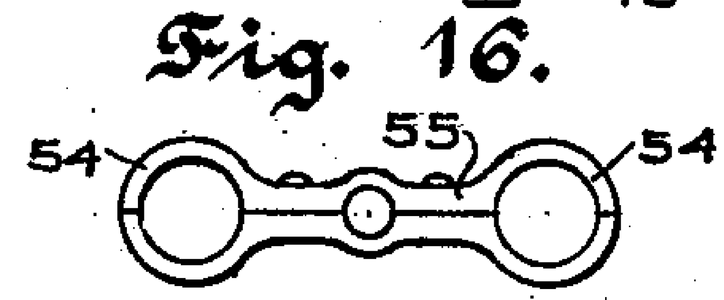

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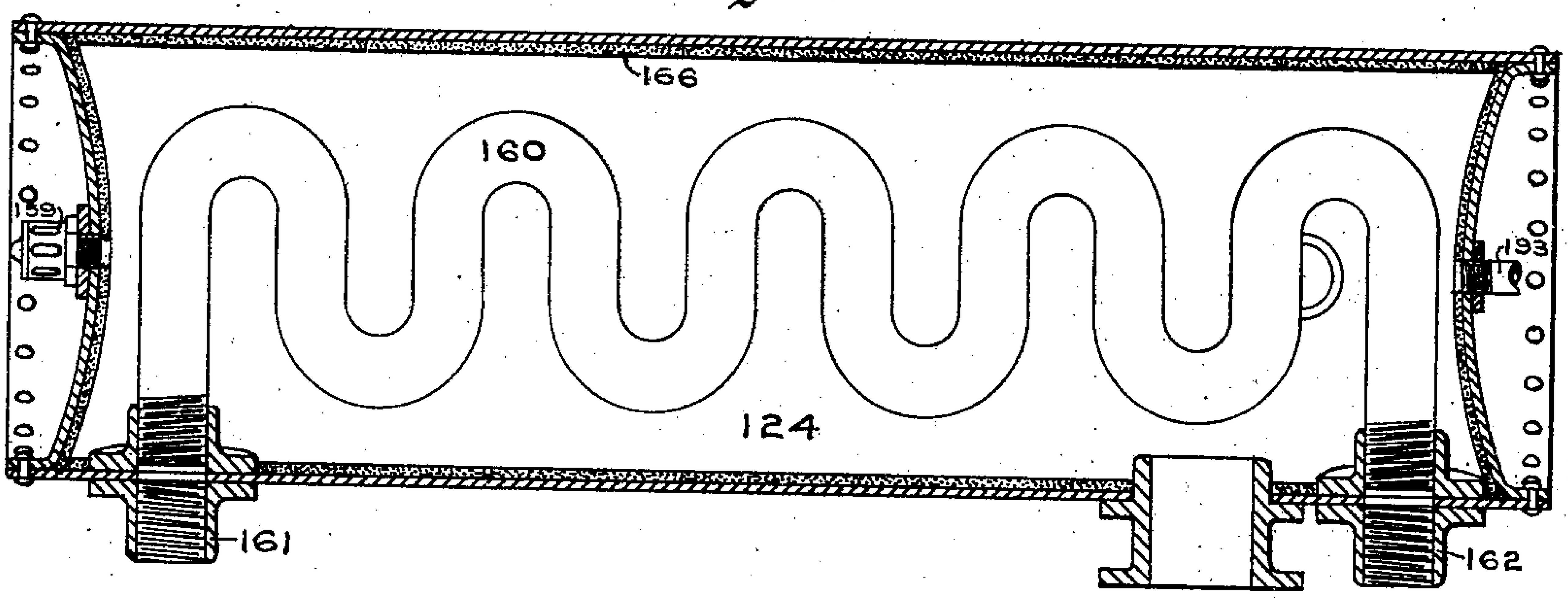
Fig. 17.



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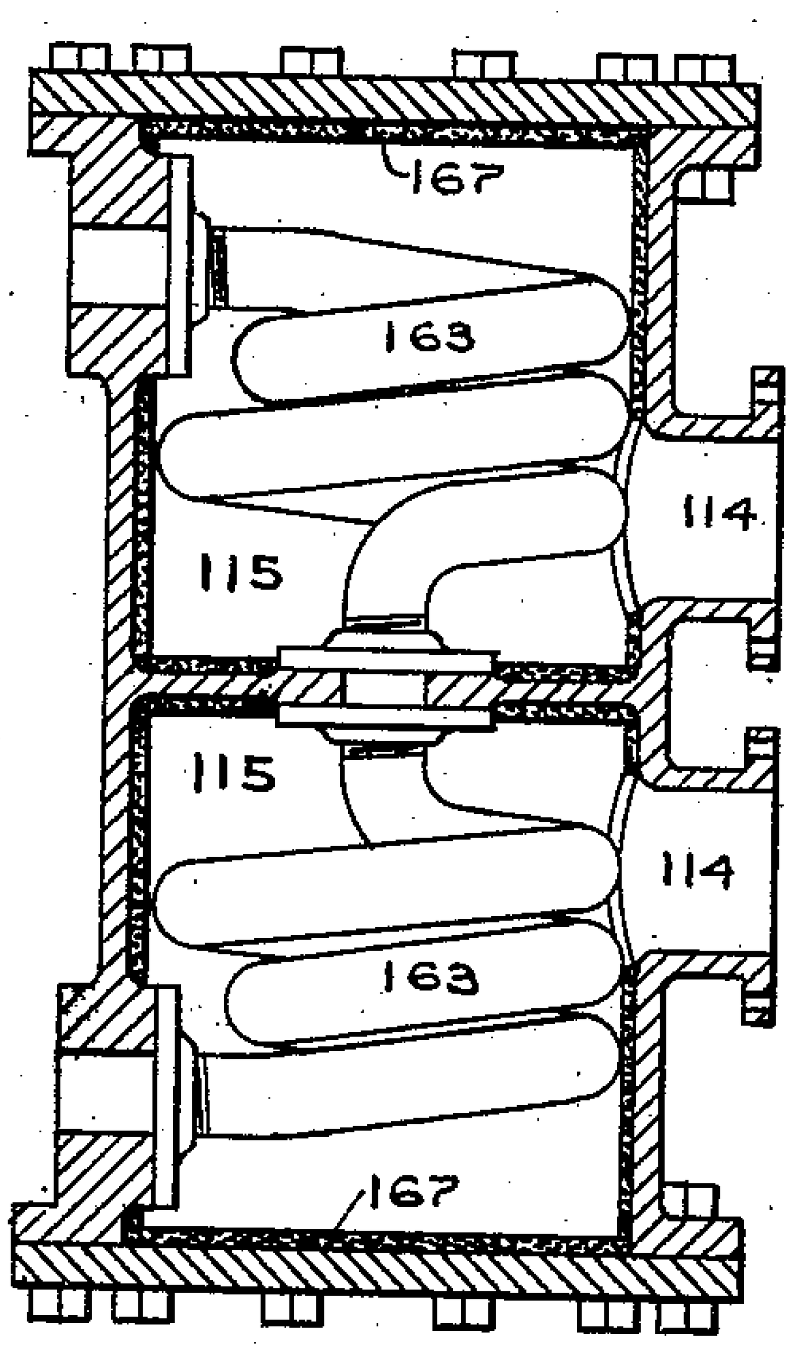

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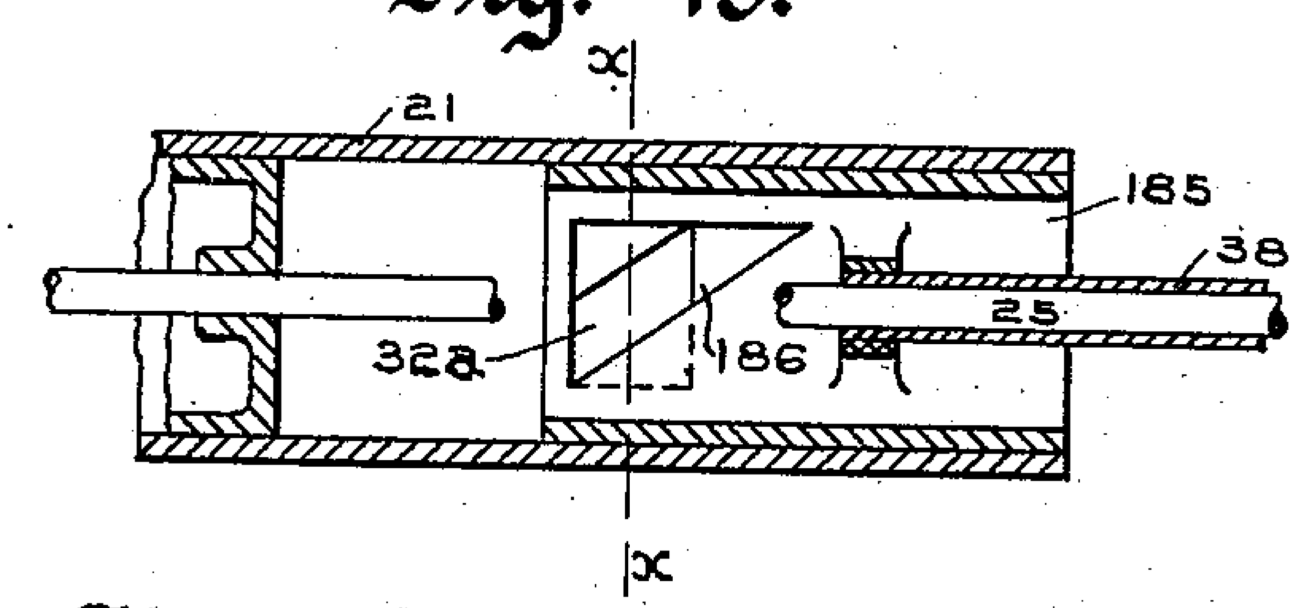

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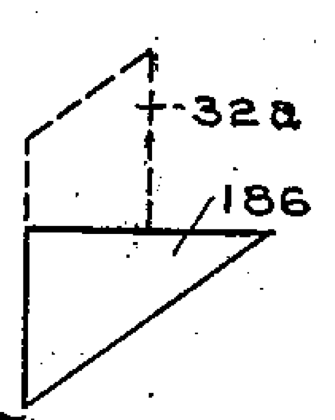

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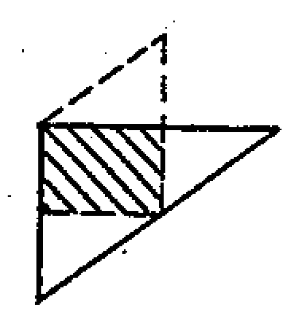

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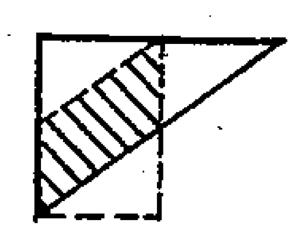

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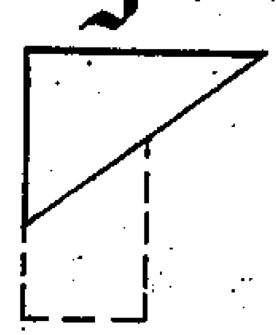

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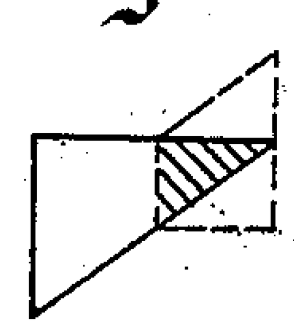

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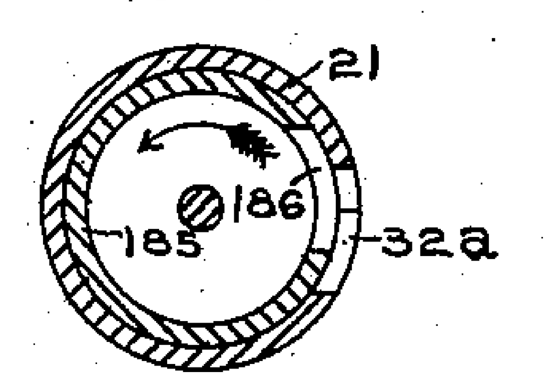

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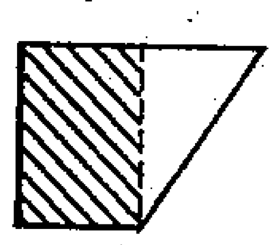

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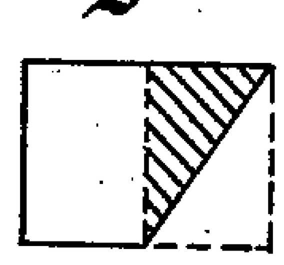

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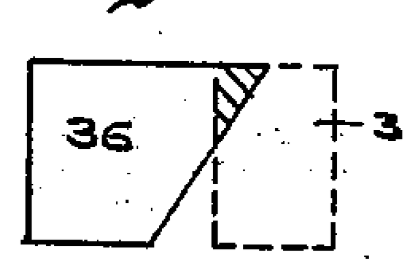

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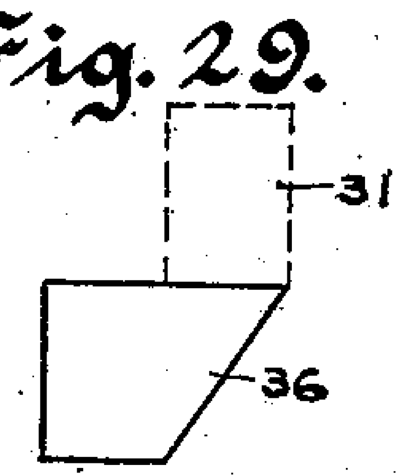

Witnesses,
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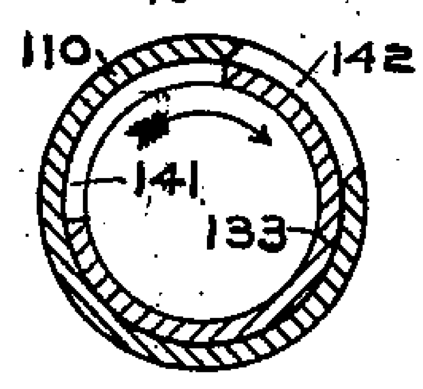
Fig. 30.



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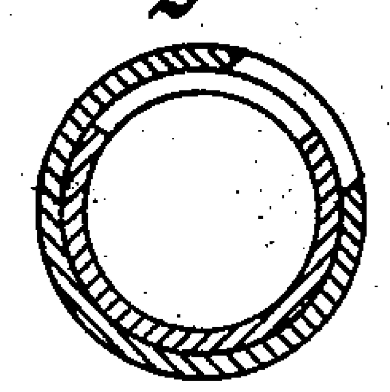

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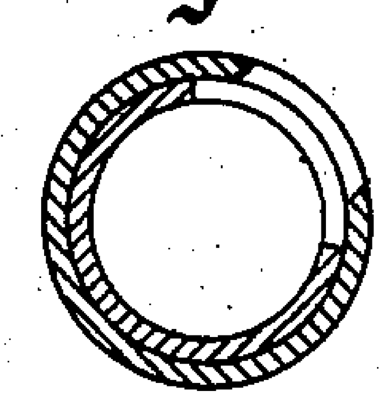

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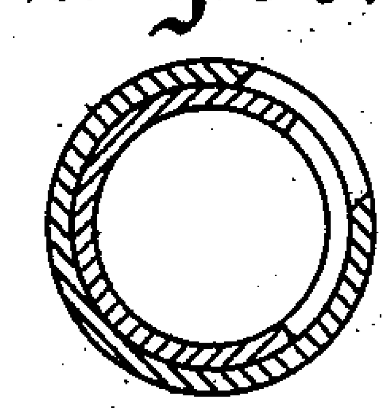

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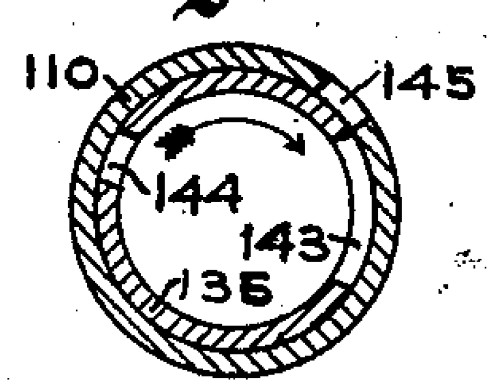

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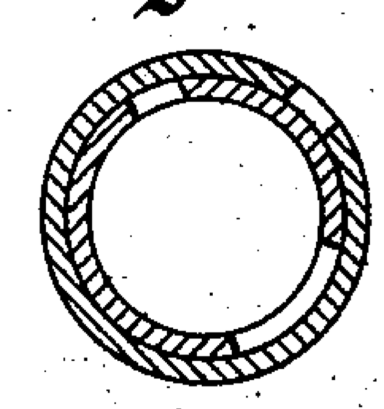

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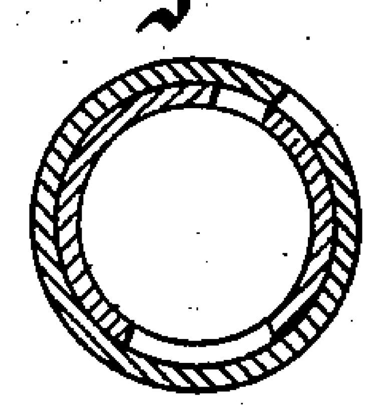

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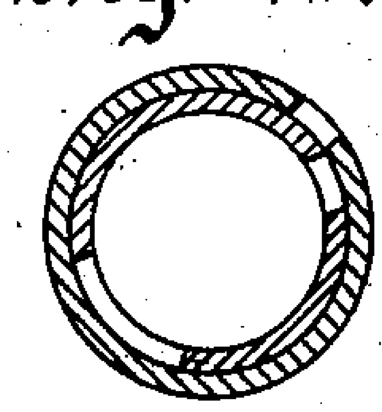

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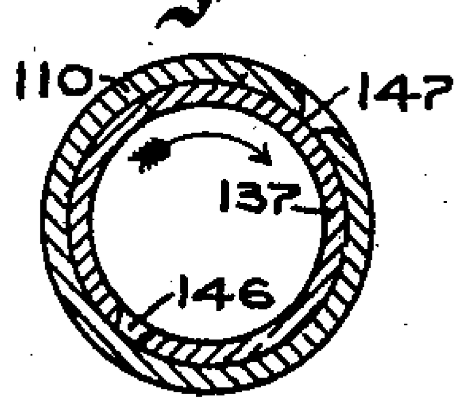

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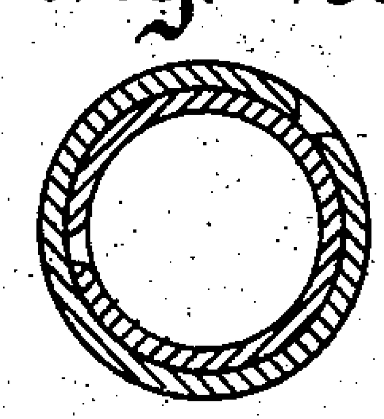

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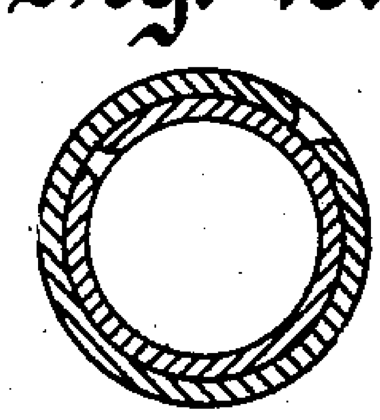

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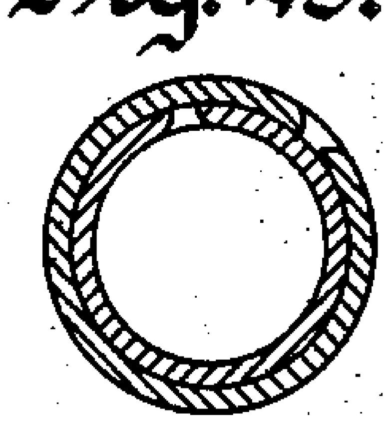

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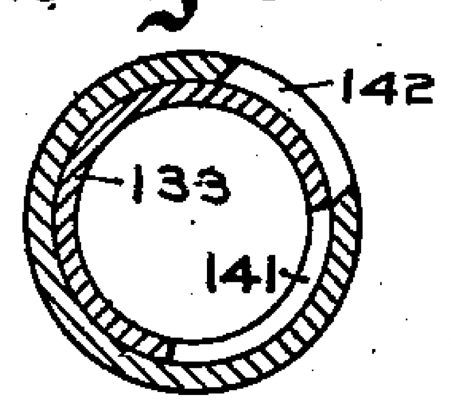

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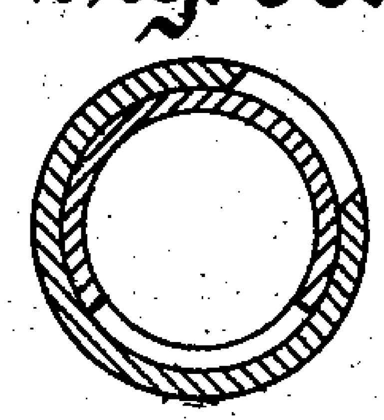

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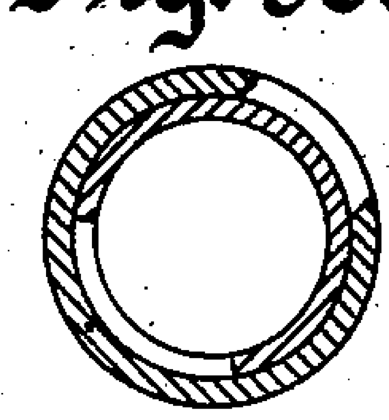

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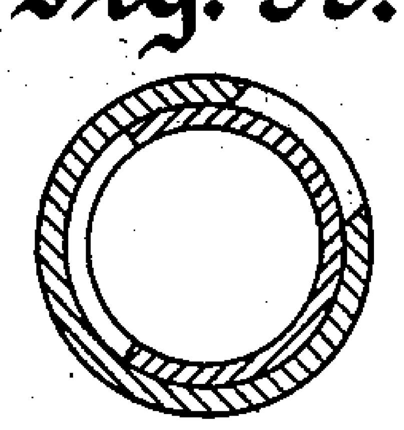

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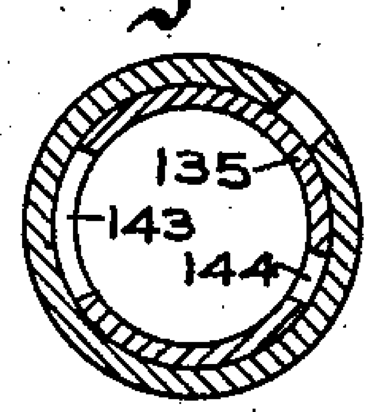

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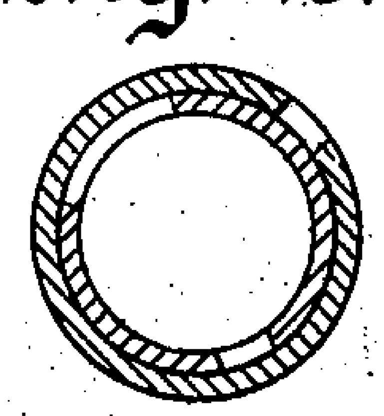

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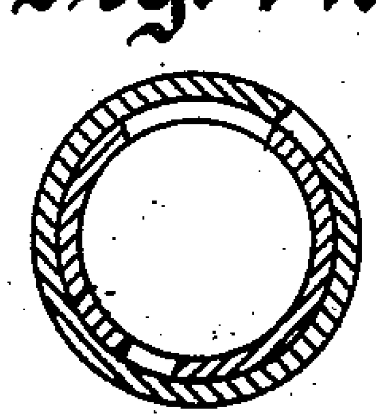

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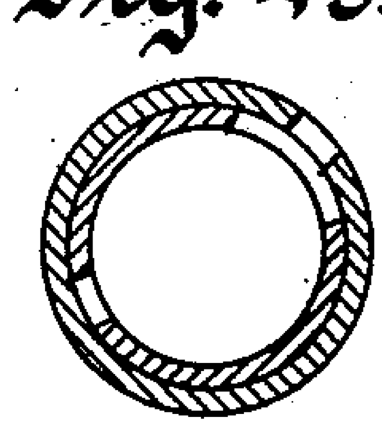

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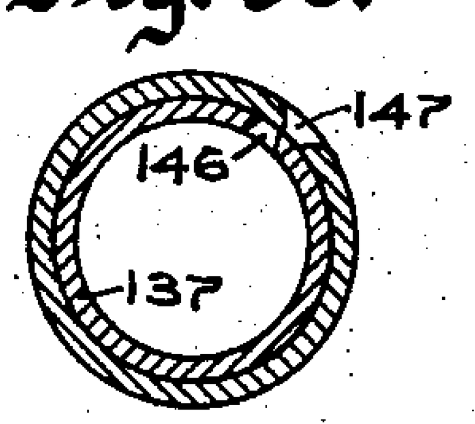

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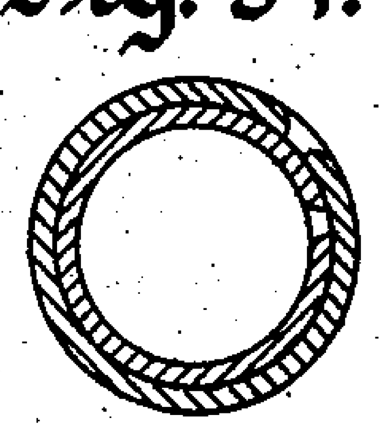

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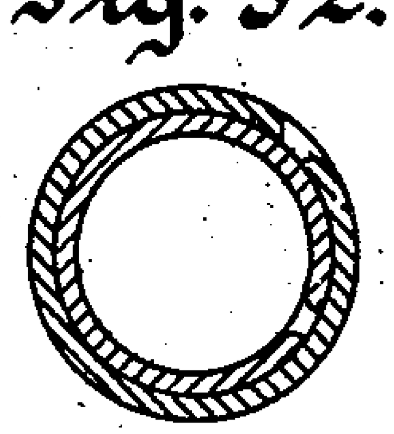

Fig. 53.

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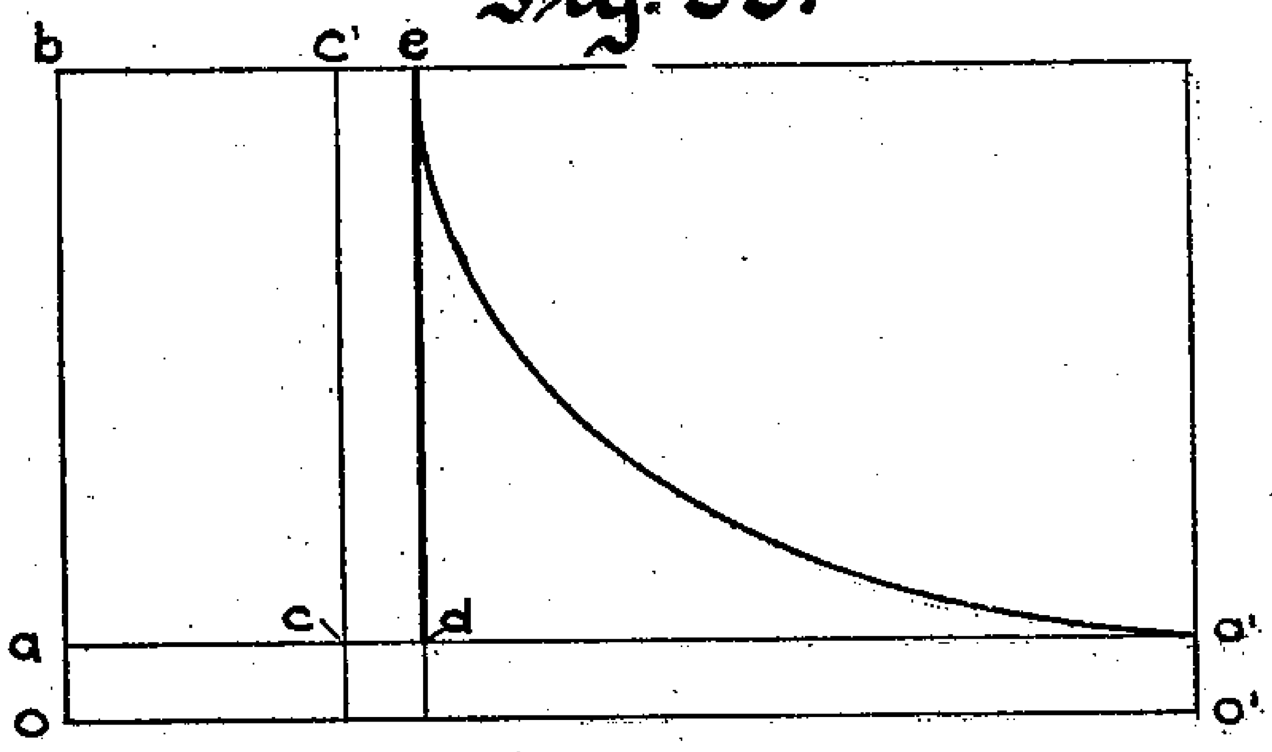
Fig. 55.



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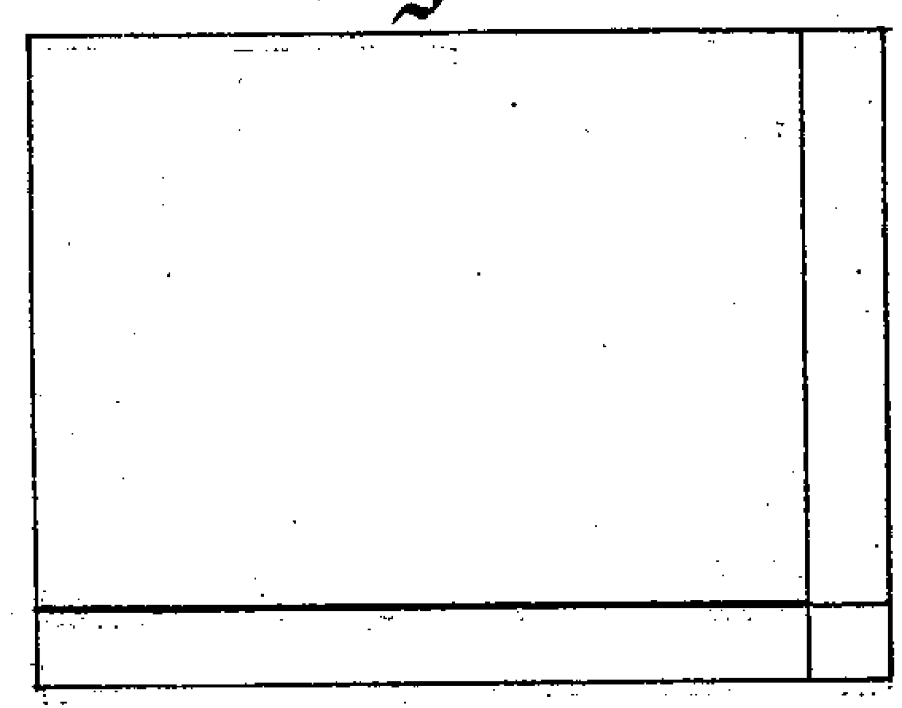

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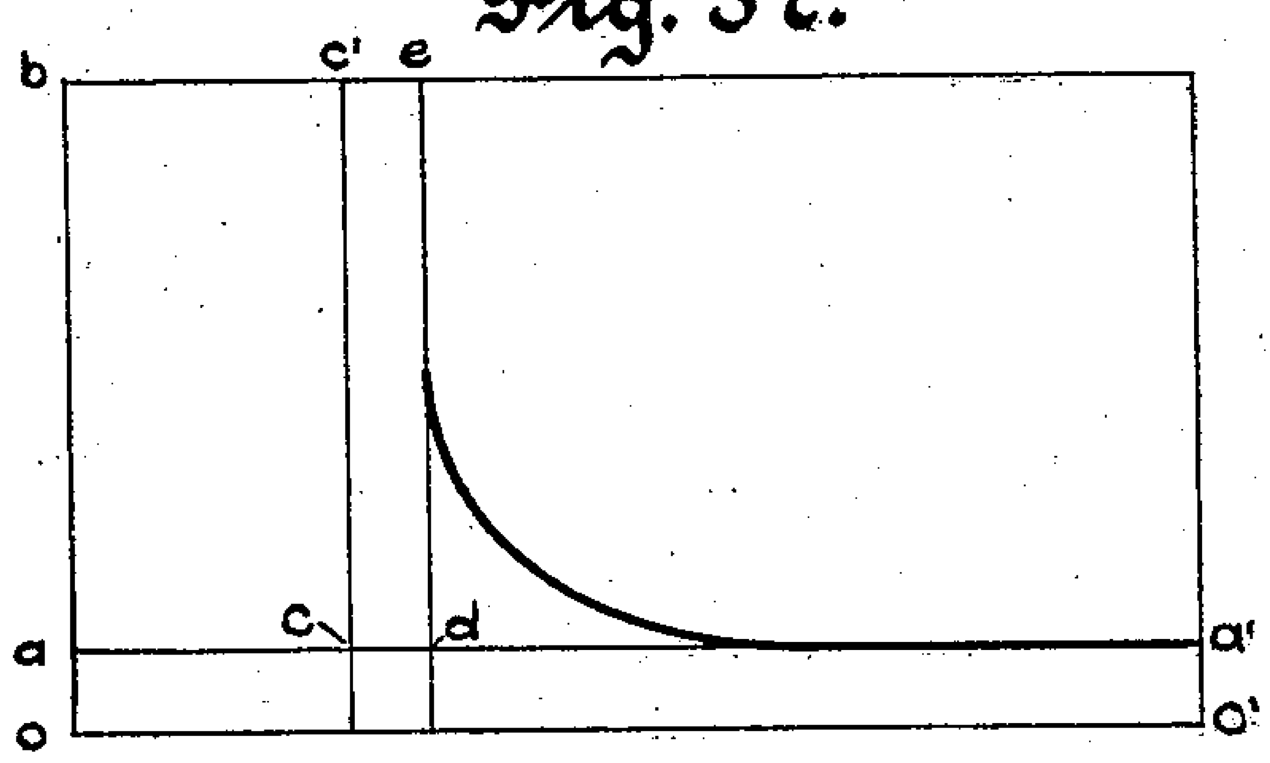

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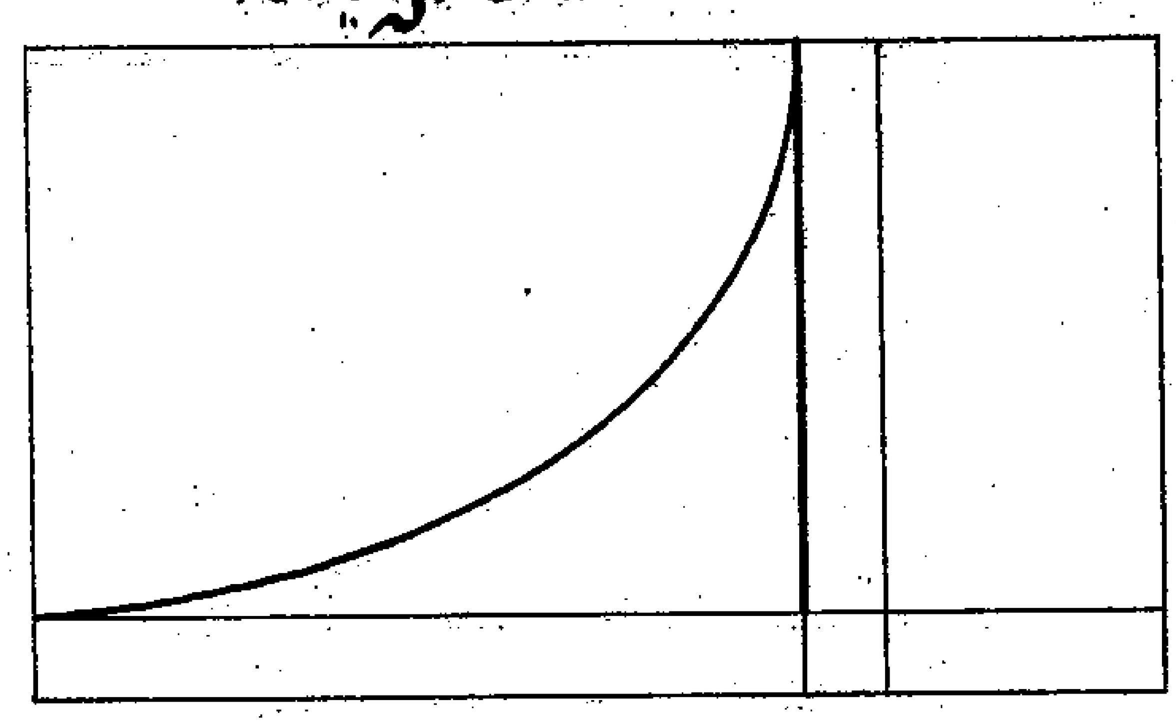

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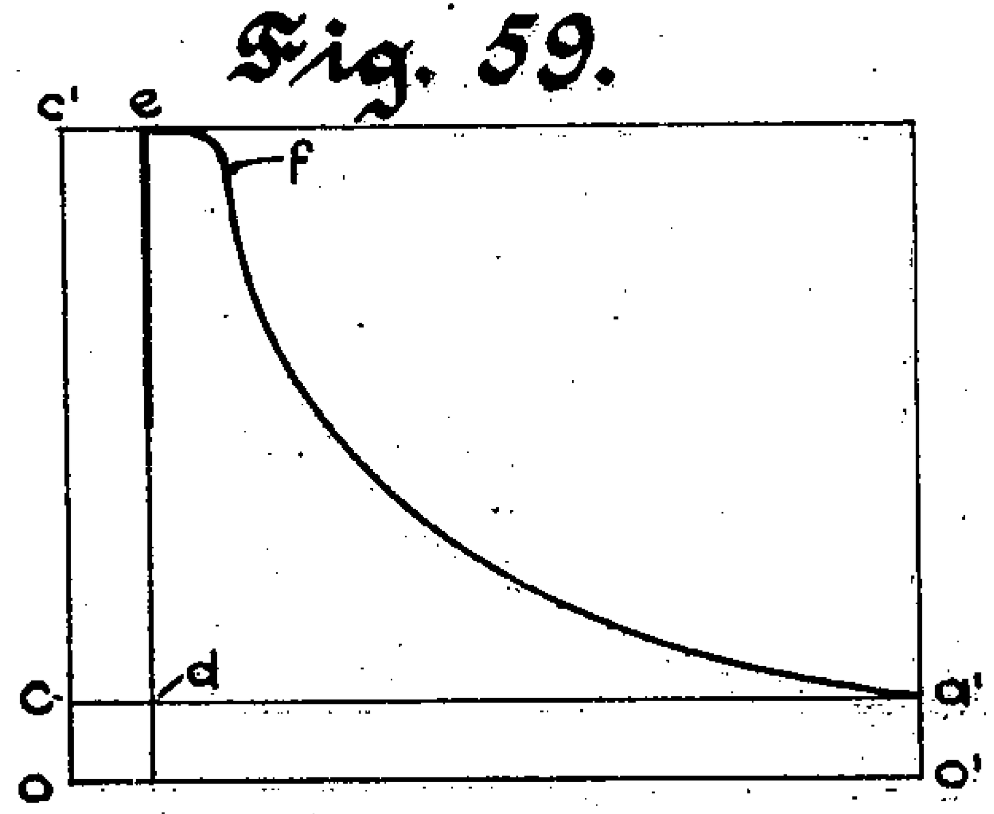

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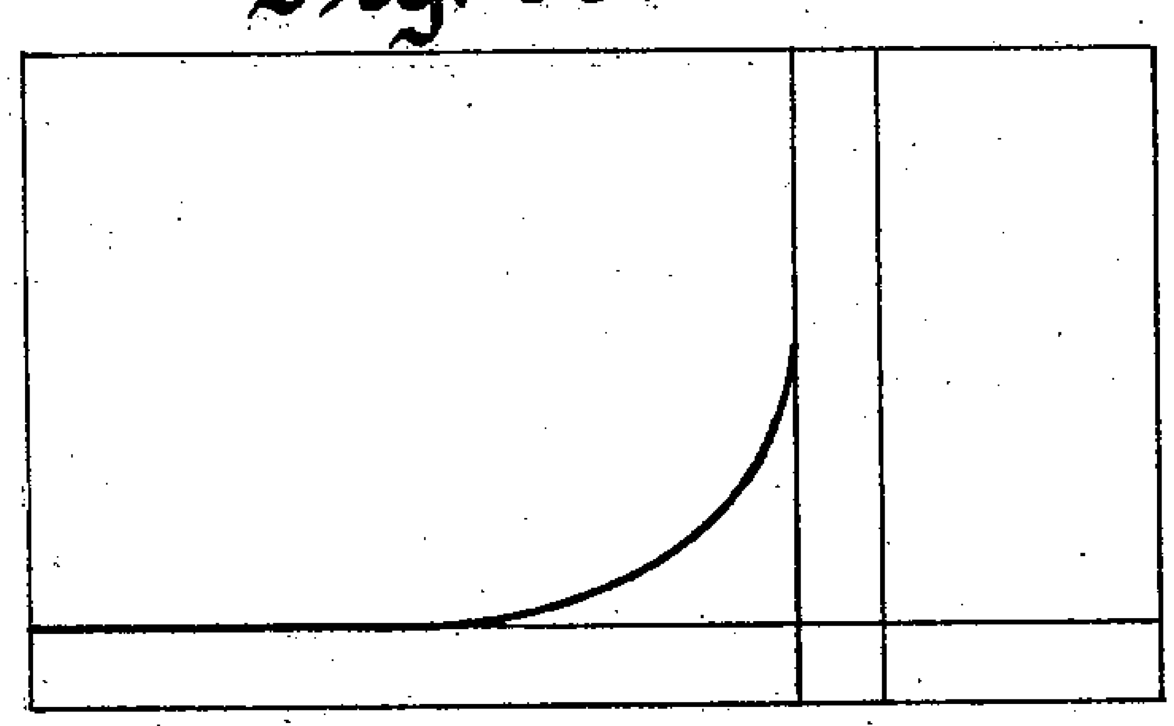

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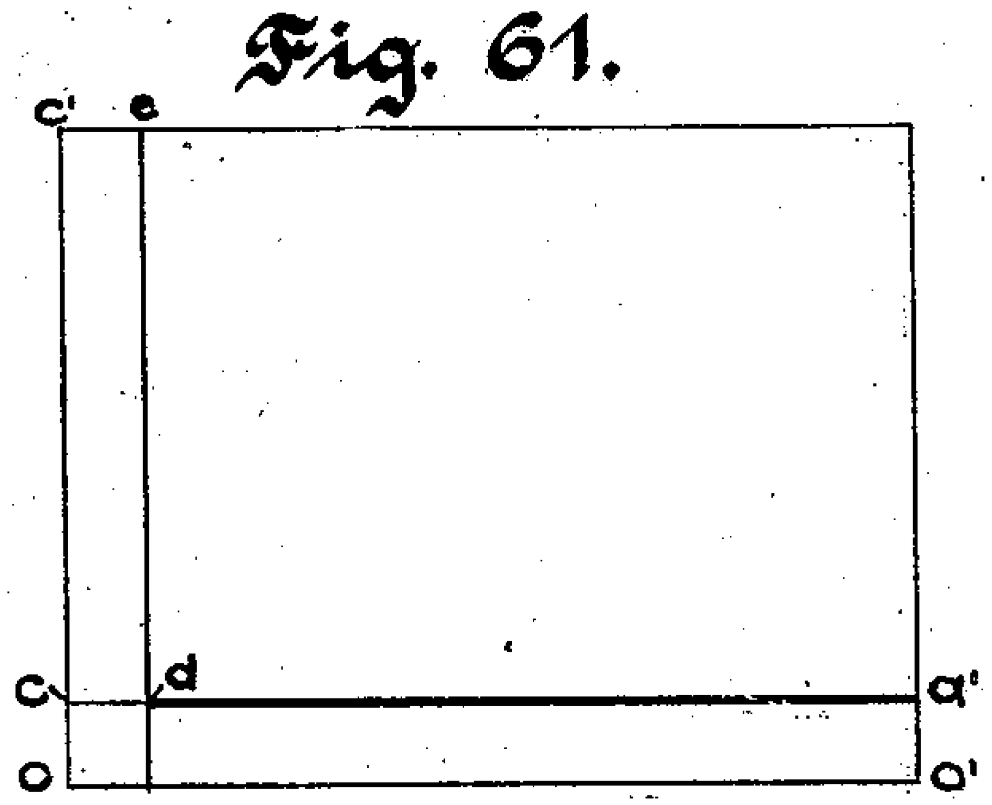

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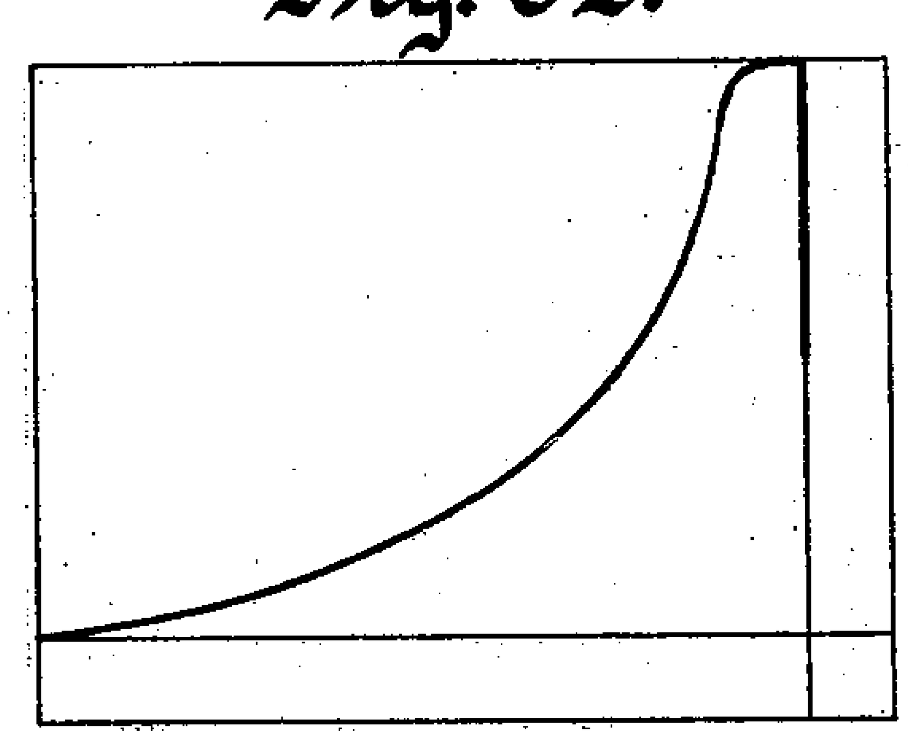

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his Attorneys.

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

UNITED STATES PATENT OFFICE.

SEVERINUS J. CORRIGAN, OF ST. PAUL, MINNESOTA.

AERO-STEAM ENGINE.

SPECIFICATION forming part of Letters Patent No. 708,027, dated September 2, 1902.

Application filed September 3, 1901. Serial No. 74,055. (No model.)

To all whom it may concern:

Be it known that I, SEVERINUS J. CORRIGAN, a citizen of the United States, residing at St. Paul, in the county of Ramsey and State of Minnesota, have invented certain new and useful Improvements in Aero-Steam Engines, of which the following is a specification.

My invention relates to improvements in aero-steam engines, consisting of an engine in which the main working fluid consists of heated air supplied from an air chamber and reservoir and regulated by suitable valve mechanism and an independent cycle in which steam is preferably the working fluid, designed for giving initial momentum to the fly-wheel and of initially compressing thereby air into the chamber and reservoir, which initially-compressed air is utilized in the beginning of the air-engine cycle. The air compressed in the chamber and reservoir is preferably heated by means of gaseous products of combustion and then allowed to expand in the main cylinder to actuate the contained piston.

The construction and arrangement of my invention are particularly shown and described in the accompanying drawings and specification, in which—

Figure 1 is a side elevation of my improved engine. Fig. 2 is an end elevation. Fig. 3 is a plan view. Fig. 4 is a vertical section through the cylinder and valves. Fig. 5 is an elevation of the same. Fig. 6 is an elevation of the steam-valve chests and valve-operating mechanism, certain portions being broken away, so as to show the contained parts. Fig. 7 is a similar view of the air-valve chests. Fig. 8 is a detail of a valve used in my engine. Figs. 9 and 10 are elevations of the governor. Fig. 11 is a diagram of the electrical connections of the governing mechanism. Figs. 12 to 16, inclusive, are details of the governing mechanism. Fig. 17 is a horizontal longitudinal section of an air reservoir or receiver used with my engine. Fig. 18 is a vertical section of an air-chamber. Fig. 19 is a detail of a modified form of steam-valve. Figs. 20 to 24 are diagrams showing relative positions of ports in said valve and its seat or casing at various periods in its operation. Fig. 25 is a transverse section of said valve and casing. Figs. 26 to 29, inclusive, are diagrams illustrating various relative positions of ports in the main and cut-off steam-valves shown in Fig. 6. Figs. 30 to 37 are sections of the main air-valve taken at certain intervals or periods of its operation. Figs. 38 to 45, inclusive, are similar sections of the air-release valve taken at the same intervals or periods. Figs. 46 to 53, inclusive, are similar sections of the auxiliary air-valve taken at the same intervals. Fig. 54 is a detail of a part of the steam-valve-governing mechanism; and Figs. 55 to 62, inclusive, are graphical respresentations of the action taking place in the engine-cylinder during its operation as an air-engine.

In the drawings, A is a frame mounted upon the base B and supporting a cylinder C and platform D. Within the cylinder C is a piston 2, of ordinary construction, connected by means of the piston-rod 3, cross-head 4, connecting-rod 5, and crank 6 to a shaft 7, these parts operating in the same manner as like parts in an ordinary steam-engine. The shaft 7 is carried in the main bearings 8 and outboard bearing 9 and has mounted upon it a fly-wheel 10, of ordinary construction.

Upon one side of the cylinder C is a steam-chest 11, the walls of which are preferably an integral part of the cylinder-casting, the interior of said steam-chest being connected with the interior of the cylinder C by the ports or passages 12. (Shown in Figs. 4 and 6.) In one end of the steam-chest 11 is a chamber 13, into which steam may be led from a boiler (not shown in the drawings) through a pipe 14 and opening 15 in the side of said chamber. At the other end of the steam-chest 11 is an exhaust-steam chamber 16, having in its side an opening 17, connecting with an exhaust-pipe 18. Between the chambers 13 and 16 are two horizontal cylindrical valve-chambers 19, having their axes parallel to each other and to the axis of the main shaft 7, each of said chambers having in its side an opening 20, connecting with its corresponding port or passage 12. These chambers 19 are preferably fitted with linings or bushings 21, which may be taken out when worn and replaced by new ones. The ends of the steam-chests 11 are closed by heads or flanges 22 and 23, secured to the main casting by means of bolts 24.

Concentrically arranged within each of the chambers 19 and extending through the heads 22 and 23 is a rotatable shaft 25, upon which are mounted a hollow cylindrical steam-valve 26 and a similar exhaust-valve 27, closely fitting in the bushing 21, and closed at their adjoining ends by webs or partitions 28 and 29, respectively, and open at their outer ends to the chambers 13 and 16, respectively. The valve 26 has at its outer end a flange 30, bearing against the end of the bushing 21 for the purpose of preventing endwise movement of said valve.

In the side of the steam-valve 26 is an opening 31, preferably of rectangular form, which at certain periods of the revolution of said valve registers with a similar opening 32 in the bushing 21, communicating with the passage 12, thus permitting the flow of steam from the chamber 13 to the interior of the cylinder C. The exhaust-valve 27 has in its side a similar opening 33, which at certain periods of its revolution registers with an opening 34 in the bushing 21, permitting the flow of exhaust-steam from the cylinder C through the chamber 16 and port 17 to the outside atmosphere.

In order to regulate the amount of steam to be admitted to the cylinder, I provide within the valve 26 a similar valve 35, somewhat shorter than the valve 26 and having in its side an opening 36, which normally registers with the opening 31 in valve 26, but is of different form, preferably trapezoidal. The valve 35 is open at both ends and is mounted by means of a spider 37 on a hollow shaft or sleeve 38, enveloping a portion of the shaft 25 and capable of being rotated and moved lengthwise thereon. The sleeve 38 extends through a stuffing-box 39 in the head 22 and terminates in a drum 40. (Shown in detail in Figs. 13 and 15.) The shaft 25 extends through and beyond the drum 40 and has slidably mounted upon its outer end a collar 41, which is prevented from turning on said shaft by a feather 42. Upon the outer end of the drum 40 is a cylindrical projection 43, loosely fitting in a corresponding socket 44 in the inner end of the collar 41 and grooved circumferentially to receive the ends of screws 45 in the collar 41, thus preventing the drum 40 and collar 41 from moving lengthwise relative to each other. Upon one side of the drum 40, near its outer end, is the lug 46, and directly opposite thereto is a lug 47, forming a part of the collar 41 and connected to the lug 46 by means of a helical spring 48, which may be adjusted by means of a screw 49 through the lug 47.

The above-mentioned parts are in duplicate, as shown.

In order to rotate the shaft 25 and the parts mounted thereon, I provide on the main shaft 7 a sprocket-wheel 50, which drives, by means of a chain 51, a sprocket-wheel 52, mounted upon the outer end of one of the shafts 25, which drives the other shaft 25 by means of the gears 53, of equal diameter, mounted upon the shafts 25. The sprocket-wheels 50 and 52 are likewise of equal diameter, and consequently the shafts 25 will rotate synchronously with the main shaft 7.

It will be seen that the cut-off valve 35 will normally rotate with the main steam-valve 26, since the sleeve 38, upon which the valve 35 is mounted, is connected by means of lugs 46 and 47 and the spring 48 to the collar 41, which must revolve with the shaft 25, as described. The collars 41 are circumferentially grooved to receive the ends 54 of a yoke 55, (shown in detail in Fig. 16,) which yoke is securely mounted upon one end of a screw 56, the axis of which is parallel to and equally distant between the axes of the shafts 25. Said screw 56 is carried by bearings 57, through which it is free to move longitudinally, but is prevented from turning therein by a feather 58, secured in one of said bearings. The bearings 57 are mounted upon a stand 59, which is supported upon the platform D. Upon the screw 56 and between the bearings 57 is a gear 60, internally threaded to fit the screw 56, so that rotation of said gear in either direction will cause a corresponding longitudinal movement of the screw 56, and consequently of the cut-off valves 35. The gear 60 engages with a pinion 61, mounted upon the shaft of an electric motor 62, (shown in Figs. 2 and 3,) said motor being supported on the stand 59.

Mounted upon a stand 63 is a brake 64, acting against the peripheries of the drums 40. The shoes 65 of the brake 64 are brought into contact with the drums 40 by means of a toggle-joint 66 and the connecting-rod 67, pivotally connected thereto and to the armature 68 of an electromagnet 69. (See Fig. 12.)

In order to control the action of the motor 62 and brake 64, I provide a governor 70. (Shown in detail in Figs. 9 and 10.) The governor consists of the following-described parts: Mounted upon the platform D is a stand 71, carrying a rotatable vertical shaft 72, on the upper end of which are lugs 73, to which are pivotally connected arms 74, carrying upon their outer ends weights 75. The arms 74 are connected, by means of rods 76, to a sleeve 77 on the shaft 72. The shaft 72 is capable of being rotated in a bearing 78 and is driven by a bevel-gear 79, engaging with a similar gear 80, mounted upon a horizontal shaft carried by the bearing 81 and having at its outer end a pulley 82, which is connected by a belt 83 to a pulley 84 on the main shaft 7. In so far as described the governor is identical in construction with the ordinary fly-ball governor.

Pivotally mounted on the frame 71 of the governor 70 is an arm 85, capable of movement in a vertical plane about its fulcrum, one end of which arm rests loosely in a circumferential groove 86 in the sleeve 77 and carrying on its side near the other end two electrical contact strips or brushes 87 and 88, which are insulated from the arm 85 and from each other. Arranged upon a plate or slab 89 of suitable insulating material, which plate is mounted upon the frame 71 of the governor, are three metallic contact-blocks 90, 91, and 92, so disposed that by an upward movement of the outer end of the arm 85 from the position shown in the drawings the brush 87 is brought into contact with the block 90, while a downward movement will bring the brush 87 into contact with the block 91, and a further downward movement will bring the brush 88 into contact with the block 92.

The electrical connections of the governing mechanism, as shown diagrammatically in Fig. 11, are as follows: 93, 94, and 95 are terminals of a three-wire electric-lighting system or other source of electrical energy, the terminals 93 and 95 being of opposite polarity and the terminal 94 opposed to both 93 and 95—*i. e.*, positive with respect to one and negative with respect to the other. Terminal 93 is connected, by means of conductors 96 and 97, to the contact-block 90 and brush 88. Terminal 94 is connected by a conductor 98 to one brush of the motor 62, the other brush of the motor being connected by a conductor 99 to the contact-brush 87. Terminal 95 is connected by conductors 100 and 101 to contact-block 91 and by conductors 100 and 102 to one terminal of the electromagnet 69, the other terminal of said magnet being connected by a conductor 103 to the block 92.

On the side of the cylinder C opposite to the steam-chest 11 is a similar chest 111, the interior of which communicates with the interior of the cylinder C by means of passages 112. At one end of the chest 111 are two compartments 113, which communicate by the openings 114 with the air-chambers 115, as shown in Fig. 18, said air-chambers having no communication with each other, these chambers consisting of two separate compartments, one of which is connected with one end of the cylinder and the other with the other end thereof through interposed valves. About the middle of the chest 111 is a chamber 116, communicating by means of the opening 117 and the valve 118 with an outlet-pipe 119. At the other end of the chest 111 is a chamber 120, communicating, by means of an opening 121, the valve 122, and pipe 123, with a compressed-air reservoir 124. Arranged within the chest 111 and extending from chambers 113 through the chamber 116 to chamber 120 are two horizontal cylindrical valve-chambers 125, having their axes parallel to the axis of the main shaft 7, each of said chambers having in its side an opening 126, communicating with its corresponding passage 112. These chambers 125 are preferably fitted with linings or bushings 110, similar to the bushings 21 in steam-chest 11, both of these bushings having openings in their sides communicating with the chamber 116. The ends of the chest 111 are closed by heads or flanges 127 and 128, which are secured to the main casting by bolts 129. Considering for purposes of description only the upper of the chambers 125 and its contained parts, the lower one being an exact duplicate of the same, the arrangement of the valves is as follows: Concentrically arranged within the chamber 125 and extending through the heads 127 and 128 is a rotatable shaft 130, one end of which is carried by a bearing 131 and the other end through a stuffing-box 132 in the head 127. Mounted upon the shaft 130 is a cylindrical valve 133, one end of which opens into the chamber 113, the other end being closed by a web or partition 134. Adjacent to the valve 133 is a similar cylindrical valve 135, one end of which opens into the chamber 116, the other end being closed by a partition 136. Between the chambers 116 and 120 is mounted on the shaft 130 a third cylindrical valve 137, one end of which opens into the chamber 120, the other end being closed by a partition 138. The valves 133 and 137 have formed upon their outer ends flanges 139 and 140, respectively, which bear against the ends of the lining 110 in order to prevent longitudinal motion of the valves and shaft 130. The valve 133 has in its side an opening 141, which at certain periods of the rotation of the valve registers with an opening 142 in the bushing 110, thus establishing communication between the chambers 113 and cylinder C. In the side of the valve 135 are two openings 143 and 144, the same being shown in Figs. 38 to 45, inclusive, which at different periods of the rotation of the valve register with an opening 145 in the lining 110, thus establishing communication between the cylinder C and the outlet-pipe 119. In the side of the valve 137 is an opening 146, (shown in Figs. 46 to 53, inclusive,) which at a certain period in the rotation of the valve registers with an opening 147 in the lining 110, thus establishing communication between the cylinder C and the air-reservoir 124. In order to rotate the shaft 130, I provide on the main shaft 7 a sprocket-wheel 148, which drives, by means of a chain 149, a sprocket-wheel 150, mounted upon one of the shafts 130, which drives the other of the shafts 130 by means of the gears 151, of equal diameter, mounted upon the shaft 130. The sprocket-wheel 140 has twice as many teeth as the sprocket-wheel 148, and therefore the shafts 130 make but one revolution, while the main shaft 7 makes two revolutions.

In order to maintain the desired pressure in the compressed-air reservoir 124, I provide an air-compressor 152, which is driven from the main shaft 7 of the engine by means of the pulley 153 on the shaft 7, a belt 154, and a pulley 155 on the shaft of the compressor 152, the cylinder 156 of the compressor 152 being connected by pipes 157 and 158 with the reservoir 124. In one end of the reservoir 124 I provide a safety-valve 159 in order to prevent the pressure within the reservoir exceeding the desired limit. Within the reservoir 124 I provide a pipe 160 of the form shown, said pipe not being open to the interior of the reservoir, but terminating externally to the reservoir in the pipes 161 and 162. In the air-chambers 115 I provide similar pipes 163, preferably coiled in helical form and connected with the external pipes 164 and 165. The object of these pipes 160 and 163 is to provide for heating the air contained in the reservoir 124 and chamber 125, respectively, by forcing heated air or gases through said pipes, using any suitable means, such as a fan, for producing circulation of such gases through these pipes. In order to restrict the conduction of heat through the walls of the reservoir 124, I provide a lining 166 of some substance, such as magnesia or mineral wool, which is a poor conductor of heat, and to restrict the radiation of heat from these walls their outer surfaces are preferably highly polished. For a like reason I provide for the walls of air-chambers 115 a similar lining 167 and polish the exterior of said walls. It will be seen that by varying the thickness of these non-conducting linings 166 and 167 I can fix the loss of heat by conduction through the walls of the reservoir 124 and air-chambers 115 at a predetermined amount.

As it is not intended that the engine shall be operated by steam and air at the same time, I provide the following means for instantaneously closing the communication between the cylinder C and the steam-chest 11 and at the same time opening communication between the cylinder C and the air-valve chest 111, or vice versa. In each of the passages 12 and 112 I provide a stop-valve 168 of the form shown in Fig. 8 and shown in section in Fig. 4. These valves fit in hollow cylindrical casings 169, which preferably form an integral part of the main cylinder-casting and which are closed at their ends by heads 170 and 171, which are bolted to the casing 169. Each of the valves 168 has projecting centrally from one end a short shaft or trunnion 172, which is free to rotate in a bearing 173 in the head 170. The other end of the valve is provided with a similar though longer shaft 174, extending through a stuffing-box 175 on the head 171 and carrying at its outer end a crank 176. To the outer ends of the cranks 176 are pivotally connected rods 177 of equal length, said rods being connected at their other ends to pins 178, set in a "bell-crank" 179, the fulcrum of which is equidistant from the axes of all the shafts 174 and which is attached to a hand-wheel 180, forming practically a part thereof, said hand-wheel and bell-crank being rotatably mounted upon a stud 181, projecting from a boss 182 on the main cylinder-casting, as shown in Fig. 3. As shown in Figs. 4 and 5, the positions of the valves 168 are such that the passages 12 between the cylinder C and steam-chest 11 are open and the passages 112 between the cylinder C and air-valve chest 111 are closed. It will be seen that if the hand-wheel 180 is turned over to the left ninety degrees the passages 12 will be closed and the passages 112 will be opened, thus causing the engine to be operated by air instead of steam.

In order to regulate the speed of my engine while it is being operated as an air-engine, I provide the butterfly-valves 118 and 122 in the pipes 119 and 123, respectively, as hereinbefore described, said valves being operated by a common stem or shaft 191, the other end of which is supported by the bearing 192 in the frame 71 of the governor and has secured to it a crank 183, which is connected by a rod 184 to the arm 85 of the governor, so that the downward movement of the arm 85 due to an acceleration in the speed of the governor will close or partly close the valves 118 and 122, thus preventing free exhaust and likewise free admission of compressed air from the reservoir 124 to the cylinder C, and consequently reducing the speed of the engine. Conversely, a reduction in the speed of the engine from the normal will, by means of the governor and its connections with the valves 118 and 122, cause these valves to be opened, thus increasing the speed of the engine.

The operation of my engine is as follows: The passages 12 being open and the passages 112 being closed, steam is admitted from a boiler (not shown in the drawings) through the pipe 14 to the chamber 13 and valves 26 and 35, the openings 31, 32, and 36 to the passage 12, thence to the interior of the cylinder C, causing the piston to be driven downward or upward, as the case may be. At or near the end of the downward stroke of the piston the upper valves 26 and 35 will have revolved sufficiently to close their ports, and the lower set of valves will then open, admitting the steam below the piston, driving it upward, this operation being practically the same as that of an ordinary steam-engine. If after the engine has attained its normal speed it should tend to further increase in speed, the weights 75 of the governor 70, thrown outward and upward by centrifugal force, will cause the sleeve 77 to rise, thereby depressing the outer end of the arm 85, making contact between the brush 87 and the block 91, thus closing the armature-circuit of the motor 62, causing the armature, and consequently the pinion 61 and gear 60, to revolve, the connections of the motor having been previously made so that such revolutions will be in the direction to cause the screw 56 to be moved inwardly—*i. e.*, toward the steam-chest 11—causing longitudinal movement of the valves 35. As a result of this movement the opening 36 in the valve 35 will no longer register with the opening 31 in valve 26, their relative positions at different stages of such movements being shown in Figs. 26, 27, and 28. Referring to said figures, the area bounded by the full lines represents the opening 36 in the valve 35 and that bounded by broken lines represents the opening 31 in the valve 26, the shaded area representing the resultant opening through which steam is permitted to pass. Fig. 26 shows the normal relative position of the two openings, as shown in Fig. 6. Figs. 27 and 28 show successive positions in which the effective port-opening is considerably reduced, and in case of Fig. 28 the cut-off will occur earlier. If the speed of the engine should then continue to increase, the brush 88 will be brought into contact with the block 92, thus closing the circuit of the electromagnet 69, operating the brake 64. The action of the brake 64 will be to retard the rotation of the drums 40, and consequently of the cut-off valves 35, such retardation bringing the opening 36 out of coincidence with the opening 31 and, as diagrammatically shown in Fig. 29, which shows the openings 31 and 36, in such position that the port is entirely closed and no steam can be admitted to the cylinder. In case the speed should fall below the normal the weights 75 by falling downward and inwardly will allow the sleeve 77 to fall, thus raising the upper end of the arm 85 and bringing the brush 87 in contact with the block 90, thus closing the circuit through the armature of the motor 62, causing the current to flow in the opposite direction to that previously obtaining. As a result the screw 56 and connected parts will move outwardly, moving the opening 36 back into coincidence with the opening 31 as far as may be necessary to bring the engine up to speed. It will be seen that as soon as the outer end of the arm 85 begins to rise from its lowest position the contact between the brush 88 and block 92 will be broken, so that the magnet 69, and consequently the brake 64, will be no longer operative, and the action of the springs 48 will cause the cut-off valve 35 to resume its normal angular position relative to the valve 26.

In Fig. 19 I have shown a modification of my steam-valve in which only one valve is used instead of the two valves 26 and 35. Referring to Fig. 19, within the bushing 21 is a hollow cylindrical valve 185, mounted upon the sleeve 38 in the same manner as the valves 35. (Shown in Fig. 6.) In using this form of valve I make the opening 32^a in the bushing 21 preferably of trapezoidal form, as shown by the broken lines in Fig. 20, and the opening 186 in the valve of triangular form and arranged as shown in Fig. 19. Figs. 20 to 24 are diagrammatic illustrations of different relative positions of the openings 32^a and 186, the opening 32^a being shown by broken lines and the opening 186 by full lines. Fig. 20 shows the valve about to open. Fig. 21 shows it still farther advanced, but still fully opened, and Fig. 23 shows it just closing. In Fig. 24 the angular position is the same as in Fig. 21; but the valve 185 has been moved lengthwise by the governor mechanism a distance equal to the width of the opening 32^a, thus decreasing the effective opening of the port and also causing the valve to cut off somewhat sooner than it would in case of Fig. 21. A section on line x x of Fig. 19 is shown in Fig. 25.

When it is desired to operate my engine by air, I first start it as a steam-engine and allow it to operate as such until it has reached normal speed and has driven the air-compressor 152 for a sufficient time to compress air in the reservoir 124 to the desired pressure. I then close the steam-passages 12 and open the air-passages 112 by means of the valves 168, as already described, when the engine will commence to operate as an air-engine. Considering only the action taking place in the upper part of the cylinder C—that is, above the piston 2—the cycle of operation is practically as follows: At the beginning of a downward stroke of the piston, which may be called the "first forward stroke," the valves 133, 135, and 137 are in the position shown in Figs. 30, 38, and 46, respectively, the direction of the rotation of these valves being indicated by the arrows in these figures. It will be seen that the main air-valve is about to open at the beginning of the stroke, the release-valve 135 having closed immediately before the beginning of this stroke. Figs. 31, 39, and 47 show the position of these valves at about the middle of this stroke. Figs. 32, 40, and 48 show the positions at the beginning of the first return or upward stroke, Figs. 33, 41, and 49 at the middle of said stroke. Figs. 34, 42, and 50 correspond to the beginning of the second downward or forward stroke, Figs. 35, 43, and 51 to the middle of said stroke, Figs. 36, 44, and 52 to the beginning of the second return stroke, and Figs. 37, 45, and 53 to the middle of said return stroke. As hereinbefore stated, these valves make one revolution during two revolutions of the main shaft of the engine, and thus a complete cycle of operations includes two revolutions of the engine. It will be seen that during the first forward stroke the cylinder is open through the valve 133 to the air-chambers 113 and 115, the valves 135 and 137 being closed. As will be seen from Fig. 40, the small opening 144 in the release-valve 135 opens at the beginning of the first return stroke and remains open until about the middle of said stroke, while the main valve 133 is opened throughout the entire stroke, closing at the beginning of the second forward stroke. As will be seen from Figs. 34 to 37, inclusive, the valve 133 remains closed throughout the second forward and return strokes, while the release-valve 135 is closed during the second forward stroke and open during the second return stroke. The auxiliary valve 137 is open for only a short period at the beginning of the second forward stroke. During the first forward stroke the air contained in the chamber 115 and there heated by means already described will be admitted to the cylinder C to allow it to expand throughout the entire stroke, as shown in the diagram Fig. 55, which is drawn to represent an indicator-card taken from the upper end of the cylinder and in which *a a'* represent the atmospheric line, *o o'* the vacuum-line, *a c* the volume of air-chamber 115, *c d* the clearance volume of the cylinder-ports, and *d a'* the cylinder volume. *a b* will then represent the pressure in the air-chamber 115 immediately before the opening of the valve 133. When this valve opens, the pressure of the cylinder at once rises, as shown by the heavy line *d e*, to that in the air-chamber, and as the piston advances the air expands adiabatically along the curve *e a'*, doing effective work on the piston. In the figure the expansion curve terminates at atmospheric pressure; but the engine may be so designed and parts so adjusted that this curve would fall below atmospheric pressure at or about the end of the stroke. In Fig. 57 is shown the action in the upper end of the cylinder during the first return stroke. It will be seen that since the exhaust-valve 135 opens at or about the beginning of this stroke and closes at or about the middle of the stroke atmospheric pressure will obtain during the first half of the stroke, while during the last half the air remaining in the cylinder and air-chamber 115 will be compressed into the air-chamber and the clearance-space. At the end of this stroke the main air-valve 133 closes and remains closed during the next two strokes, thereby confining the air compressed into the chamber, which is there heated by the means already described and the pressure thereby materially increased. At the beginning of the second forward stroke the auxiliary air-valve 137 opens and remains open during a small portion of the stroke, other communications with the cylinder being closed. Compressed air is thus admitted from the reservoir 124 to the cylinder. This air, together with that compressed by the piston in the clearance-space during the preceding stroke, will then expand, as indicated by the curve *f a'*, Fig. 59, to or below atmospheric pressure. During the second return stroke, the exhaust-valve 135 being open and other valves closed, the pressure in the upper end of the cylinder will be that of the atmosphere, as illustrated in Fig. 64. Opposite each one of the Figs. 55, 57, 59, and 61 are shown the corresponding diagrams for the other end of the cylinder, Figs. 56, 58, 60, and 62. It will be seen that the stroke which in the upper part of the cylinder is the first forward is the second return or exhaust in the lower part. The first return in the upper end is the first forward in the lower end, the second forward in the upper is the first return in the lower, and the exhaust in the upper is the second forward in the lower end. It will be obvious that it is not necessary that the first stroke of the engine when starting should be what I have here designated as the "first forward stroke;" but any portion of the cycle may be considered as the beginning thereof.

In order to facilitate the operation of the engine during the first forward stroke on each side of the piston at the beginning of the initial air-cycle—that is, when changing from steam to air as a working fluid—I provide the small pipe 193, leading from the air-reservoir 124 and provided with branches 194 and 195, opening into the air-chambers 115, these branches being provided with stop-valves 196 and 197. By this means the air-chambers 115 can be filled with compressed air while the engine is being operated by steam. When the air-chambers 115 are so filled and before changing from steam to air as a working fluid, the valves 196 and 197 will be closed, preventing any further communication between the reservoir 124 and air-chambers 115. The ratio of expansion of air from the air-chambers 115 into the cylinder C during each forward stroke is greater than the ratio of compression of said air into said chambers 115 during the latter part of each first return stroke, and the ratio of expansion of the air from the reservoir 124 into the cylinder C during the second forward stroke is greater than the ratio of compression of said air into said reservoir 124 by the compressor 152, the total energy developed by the expansion being greater than the total energy consumed in compression, the surplus energy being available for external work, thus utilizing the heat supplied to the working fluid (air) by means of the heated gases circulating through the pipes 160 and 163 in the reservoir 124 and air-chambers 115.

I claim—

1. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber, heating means therefor, and valves interposed between said air-chamber and piston-cylinder said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber and the clearance-space of the cylinder, during the latter half of the second stroke of the cycle, retained in said chamber and heated therein during the third and fourth strokes of the cycle, and expanded from said chamber into the cylinder during the first stroke of the following cycle.

2. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber, heating means therefor, and valves interposed between said air-chamber and piston-cylinder said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber and the clearance-

space of the cylinder during the latter half of the second stroke of the cycle, retained in said chamber and heated therein during the third and fourth strokes of the cycle, and expanded from said chamber into the cylinder during the first stroke of the following cycle, and means for giving initial movement to the piston.

3. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber, heating means therefor, and valves interposed between said air-chamber and piston-cylinder, said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature, into said chamber and the clearance-space of the cylinder, during the latter half of the second stroke of the cycle, retained in said chamber and heated therein during the third and fourth strokes of the cycle, and expanded from said chamber into the cylinder during the first stroke of the following cycle, and means for giving initial movement to said piston.

4. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber divided into two compartments, heating means therefor, and valves interposed between said air-chamber compartments and piston-cylinder said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said chamber and the clearance-space of the cylinder, during the latter half of the second stroke of the cycle, retained in said chamber and heated therein during the third and fourth strokes of the cycle, and expanded from said chamber into the cylinder during the first stroke of the following cycle, and means for causing initial compression of air in the air-chamber and clearance, substantially as set forth and described.

5. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder and piston contained therein, a connected crank-shaft, an air-chamber divided into two compartments, heating means therefor, and valves interposed between said compartments and piston-cylinder, said parts being so constructed and arranged that air is adiabatically compressed by the piston into the clearance-space of the cylinder during the second stroke of the cycle, and expanded into the cylinder during the third stroke of the cycle, thereby doing positive work against the piston during the said stroke, the ratio of expansion during said stroke of the cycle being greater than the ratio of compression of the air in the second stroke thereof, whereby the positive energy of the air expanding in the third stroke is greater than the energy consumed in compressing said air in the second stroke, and means for imparting an initial momentum to said piston, thereby compressing air into said clearance during the second stroke of the initial cycle, substantially as set forth and described.

6. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber divided into two compartments, means for heating the contents of said chamber, an air-reservoir, means for heating the contents thereof, means for compressing air in said reservoir, valves arranged between said air-chamber compartments and reservoir and said cylinder, whereby the air is admitted from said reservoir to the cylinder during a short part of the beginning of the third stroke and expanded therein against the piston doing positive work during said stroke, the ratio of compression of said air into the reservoir being less than the ratio of expansion of said air in the cylinder during the third stroke of the cycle, whereby the energy derived from the expansion of said air during the said stroke of the cycle is greater than the energy consumed in compressing said air into said reservoir, means for initially compressing the air in said reservoir, and means for imparting initial movement to the operating parts of the engine.

7. The combination in an engine in which four strokes of the piston and two revolutions of the crank-shaft are comprised in a working cycle, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber comprising two independent compartments, one connected with one end of said cylinder, and the other with the other end, means for heating the air in said compartments, valves interposed between each compartment of said air-chamber and said cylinder, an air-reservoir, a compressor arranged in connection therewith, valves interposed between said reservoir and cylinder, the parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into each compartment of said air-chamber and the clearance-space of said cylinder during the latter part of each alternate return stroke of said cycle and heated therein during the second forward stroke and second return stroke of said cycle and expanded from each of said compartments alternately into the cylinder down to or below atmospheric pressure and temperature, the ratio of expansion in the first forward stroke being greater than the ratio of compression in the first return stroke, whereby the energy derived from the expansion of the air in said first forward stroke is greater than the energy consumed in compressing said air during the latter part

of the first return stroke, and the ratio of expansion of the air from the reservoir into the cylinder during the second forward stroke being greater than the ratio of compression of said air into said reservoir by the compressor, whereby the energy developed by said expansion is greater than the energy consumed in said compression, means for regulating the flow of air between said cylinder and air-chamber and external atmosphere, and between the compressor and the reservoir, and a governor for operating said regulating means, substantially as and for the purpose described.

8. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber, means for heating the contents of said chamber, an air-reservoir, means for compressing air therein, means for heating the contents thereof, valves arranged between said chamber and reservoir and cylinder, said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber and the clearance-space of the cylinder, retained and heated in said chamber, and expanded from said chamber into said cylinder, and is admitted from said reservoir to said cylinder during the strokes of the cycle.

9. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber, means for heating the contents of said chamber, an air-reservoir, means for compressing air in said reservoir, means for heating said air, and rotary valves for establishing communication between said air-chamber, said reservoir and said piston-chamber, said parts being so arranged and connected that air is compressed by the piston into said air-chamber, retained and heated in said chamber, expanded from said chamber into said cylinder, and is admitted from said reservoir into said cylinder during the strokes of the cycle.

10. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber consisting of two compartments, means for heating the contents of said compartments, an air-reservoir, means for compressing air in said reservoir, means for heating said air, a rotary valve for establishing communication between said air-chamber compartments and cylinder, said valve being provided with ports for establishing communication between said cylinder and the outer air, a rotary valve for establishing communication between said reservoir and cylinder, said parts being so arranged and connected that air is compressed by the piston into said chamber, retained and heated therein, and expanded from said chamber into said cylinder, and is admitted from said reservoir into said cylinder during the strokes of the cycle.

11. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber consisting of two compartments, means for heating the contents thereof, rotary valves for establishing communication between said compartments and the opposite ends of said cylinder, said valves being provided with ports for establishing communication between said cylinder and the outside air, an air-reservoir, means for compressing air therein, means for heating the same, and rotary valves for establishing communication between said reservoir and cylinder, said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber, retained and heated in said chamber, and expanded from said chamber into said cylinder, and is admitted from said reservoir into said cylinder during the strokes of the cycle.

12. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber consisting of two compartments, means for heating the contents of said chamber, an air-reservoir, means for compressing air in said reservoir, means for heating said air, rotary valves for establishing communication between the compartments of said air-chamber and said cylinder, and between said reservoir and cylinder, a source of steam-supply, and rotary valves for establishing communication between said steam-supply and cylinder, said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber compartments, retained and heated in said compartments, and expanded therefrom into said cylinder, and is admitted from said reservoir to said cylinder during the strokes of the cycle, steam being admitted to said cylinder to impart initial movement to said piston.

13. The combination in a double-acting engine, in which four strokes of the piston, *i. e.* a first forward stroke, a first return stroke, a second forward stroke, a second return stroke, and two revolutions of the crank-shaft constitute a cycle of operations, of a cylinder, a piston contained therein, a connected crank-shaft, two independent air-chamber compartments connected with opposite ends of the cylinder, means for heating the contents of said compartments, an air-reservoir, means for heating the contents thereof, a compressor actuated by the engine for forcing air into said reservoir, two sets of coöperating air-valves actuated by the engine interposed between the air-chamber compartments, air-reservoir and the cylinder, one set for each end of the cylinder, each of said air-valves being in three divisions, one valve in the first division of each set having a port to open communication between each air-chamber compartment and the corresponding end of the cylinder, during the two first strokes of each cycle, viz. the first forward and the first return, one valve in the second division of each set having two ports one of which

opens communication between the cylinder and the external atmosphere, in each last stroke of each cycle, viz. the second return stroke, and the other of which opens communication between the cylinder and the external atmosphere during the first part of each first return stroke, a valve in the third division of each set having a port which opens communication between the air-reservoir, and each end of the cylinder, during the first part of each third stroke of each cycle, viz. the second forward, the parts being so arranged and connected that air is compressed by the piston in the engine-cylinder into each air-chamber compartment during the latter half of each first return stroke, retained in each compartment and heated therein during the second forward and second return strokes, and admitted into the cylinder in each first forward stroke, and expanded into said cylinder during the said stroke down below atmospheric pressure and temperature, the parts being also arranged and connected so that air is compressed by the compressor during the working of the engine into the reservoir, from which it is admitted into each end of the cylinder during the first part of each second forward stroke, and then expanded into said cylinder down below atmospheric pressure and temperature during the remainder of said stroke, a valve controlling communication between the cylinder and the external atmosphere, a valve controlling communication between the compressor and air-reservoir, a governor for said valves actuated by the engine, a steam-boiler, auxiliary valves actuated by the engine for controlling communication between said boiler and the cylinder to regulate the influx of steam into the cylinder and the efflux therefrom for the purpose of starting the engine, a system of four coöperating stop-valves, two of which are interposed between the cylinder and the air-valve chest, the other two being interposed between each end of the cylinder and steam-valve chests, and means for actuating said valves simultaneously to throw the steam-valves into communication with the cylinder and cut the air-valves out of communication, or to throw the air-valves into communication and cut the steam-valves out.

14. The combination in a double-acting engine, in which four strokes of the piston, viz. a first forward stroke, a first return stroke, a second forward stroke, and a second return stroke, and two revolutions of the crank-shaft constitute a cycle of operations, of a cylinder, a piston contained therein, a connected crank-shaft, two air-chamber compartments, means for heating the contents of said compartments, an air-reservoir, means for heating the contents of said reservoir, a compressor actuated by the engine to force air into said reservoir, air-valve chests interposed between each end of the cylinder and the air-chamber compartment and reservoir, hollow cylindrical rotary valves arranged in each of said chests, said valves being fixed upon and rotatable by a shaft, gear connection between said valve-shafts and the crank-shaft, said gearing being so arranged and proportioned that said air-valves will make one revolution while the crank-shaft makes two, and the air-valves in each of said chests being in three divisions, a valve in the first of each division in each chest having a port for establishing communication between the air-chamber compartments and the end of the cylinder connected therewith, during the first forward and first return strokes of each cycle, a valve in the second division in each chest having two ports through one of which communication is established between the cylinder and the external atmosphere during each second return stroke of each cycle, and through the other of which valves communication is established between said cylinder and the atmosphere during the first part of each first return stroke of each cycle, a valve in the third division of said chest having a port through which communication is established between the air-reservoir and the cylinder during the first part of each second forward stroke of each cycle, a valve controlling communication between the cylinder and the external atmosphere, a valve controlling communication between the air-reservoir and cylinder, a governor for said valves actuated by the engine, whereby the flow of air between the cylinder and the external atmosphere, and between the reservoir and the cylinder may be regulated and the speed of the piston, while the latter is actuated upon by air-governed, pipe connections between the reservoir and each chamber-compartment, stop-valves for said connections, and means for initially compressing air in said reservoir and air-chamber compartments.

15. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber, means for heating the contents of said chamber, valves for establishing communication between said chamber and the cylinder, an air-reservoir, means for compressing air therein and valves for establishing communication between said reservoir and cylinder, said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber, retained and heated in said chamber, and expanded therefrom into said cylinder, and is admitted from said reservoir to said cylinder during the strokes of the cycle, and means for imparting initial movement to said piston.

16. The combination in an engine, of a cylinder, a piston contained therein, a connected crank-shaft, an air-chamber consisting of two compartments, means for heating the contents of said compartments, an air-reservoir, means for compressing air in said reservoir, means for heating the air, valves for establishing communication between said air-chamber compartments and cylinder, and for es-

tablishing communication between said reservoir and cylinder, said parts being so arranged and connected that air is compressed by the piston from atmospheric pressure and temperature into said air-chamber compartments, retained and heated in said compartments, and expanded therefrom into said cylinder, and is admitted from said reservoir to said cylinder during the strokes of the cycle, a source of steam-supply, and means for admitting steam to said cylinder to impart initial movement to said piston.

In testimony whereof I affix my signature in presence of two witnesses.

SEVERINUS J. CORRIGAN.

Witnesses:

H. S. JOHNSON,

C. J. MCCONVILLE.