

No. 654,789.

Patented July 31, 1900.

D. MCGILL & F. W. TANNETT-WALKER.

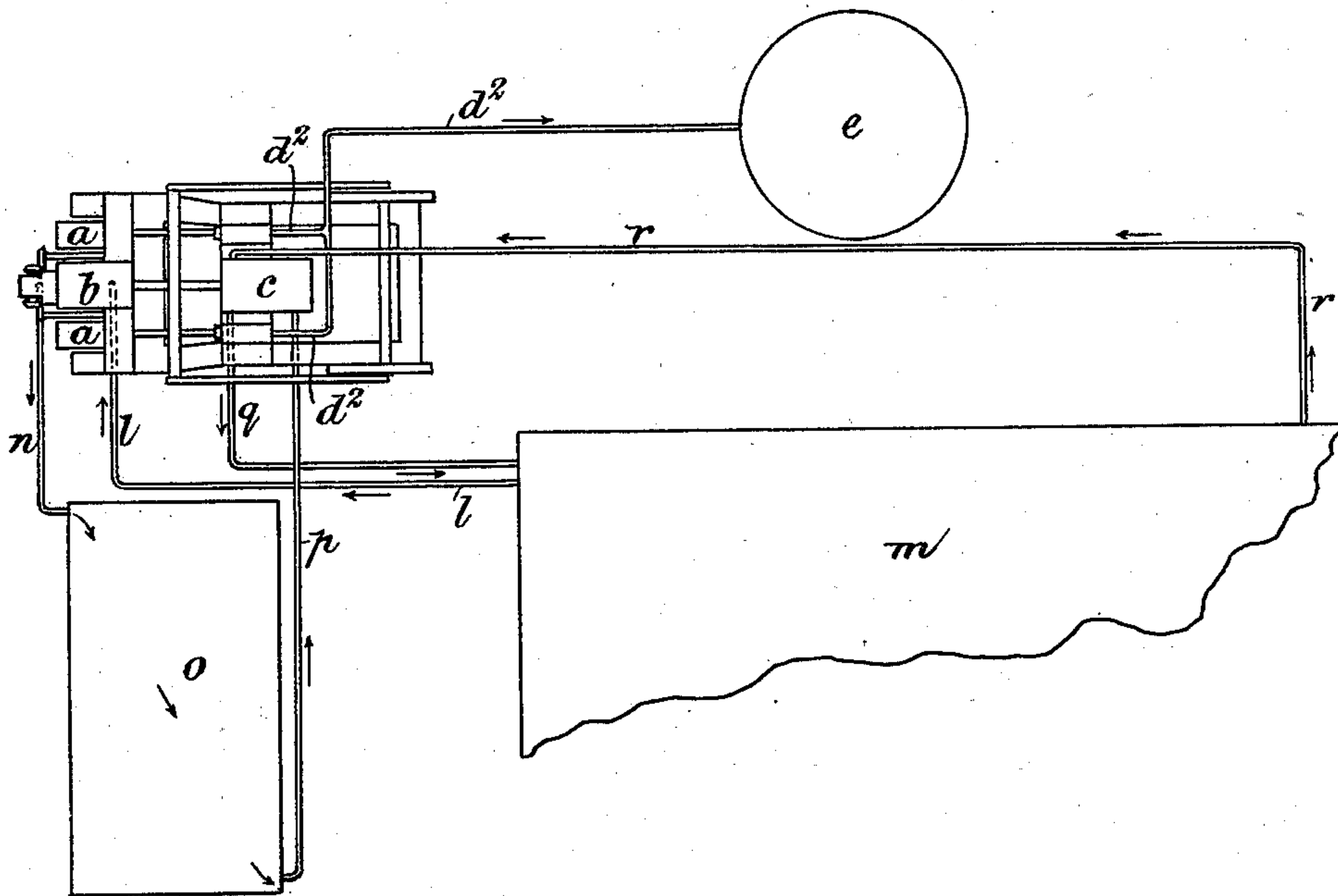
REFRIGERATING MACHINE.

(Application filed Jan. 31, 1899.)

(No Model.)

4 Sheets—Sheet 1.

Fig. 1.



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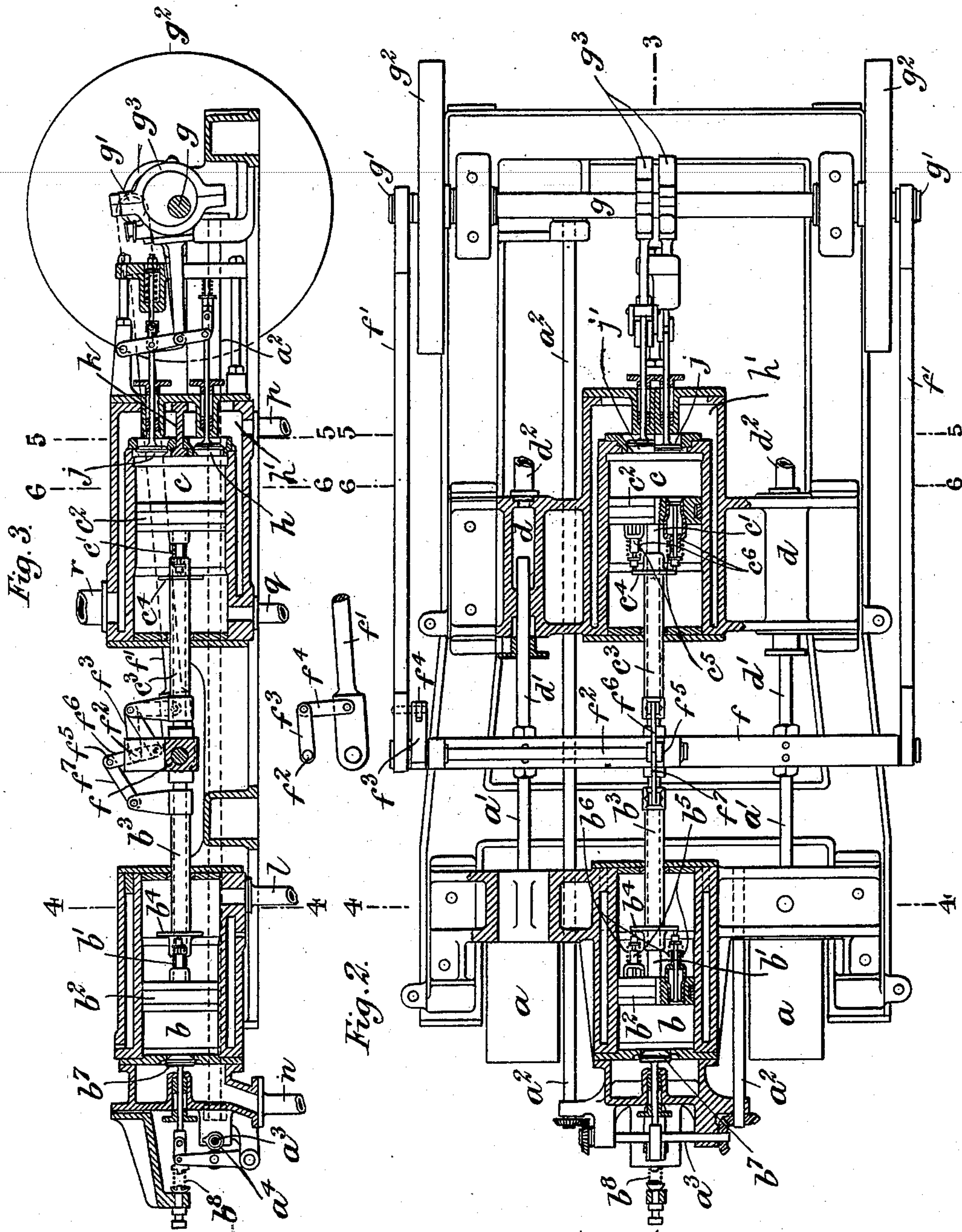
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4 Sheets—Sheet 2.



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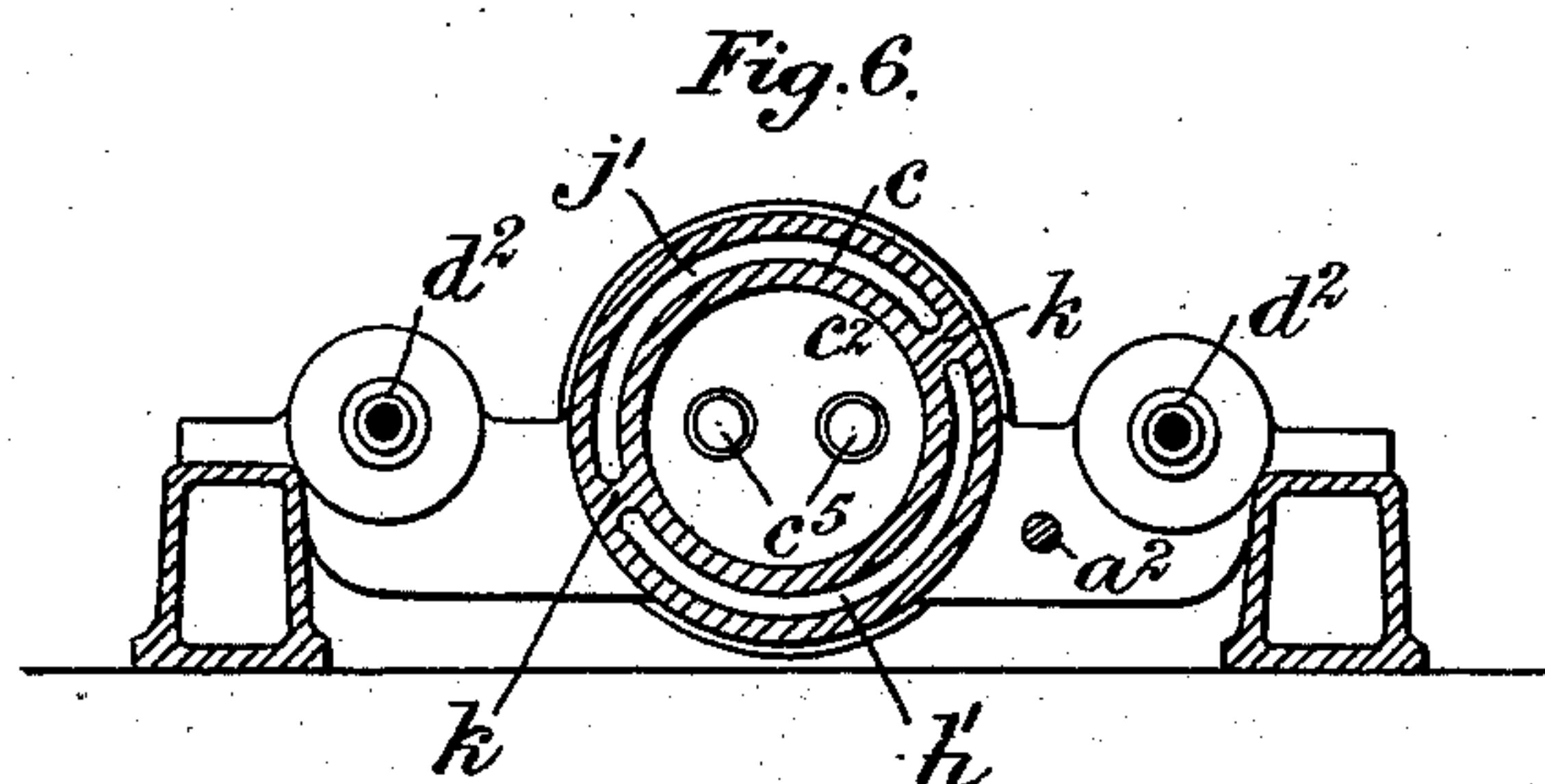
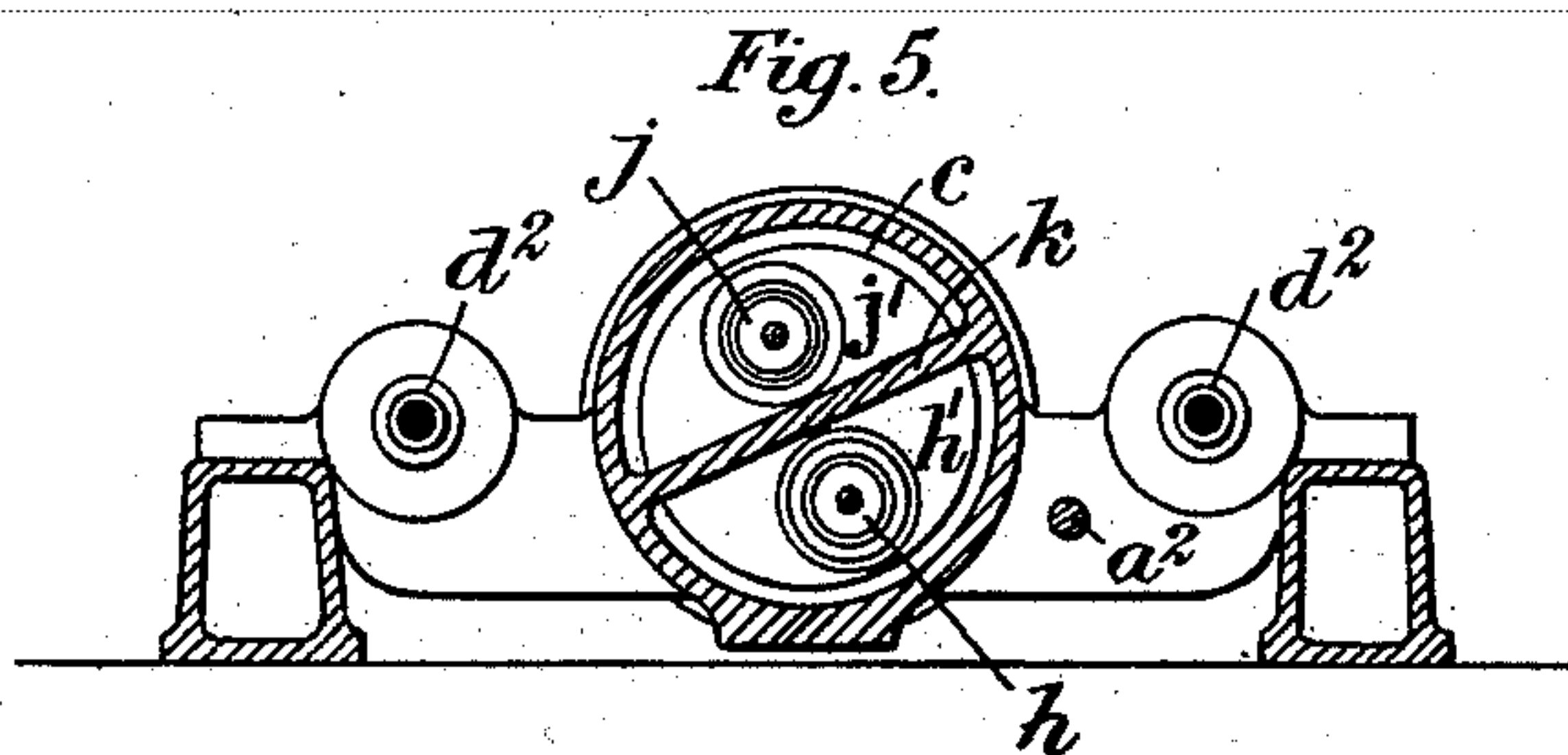
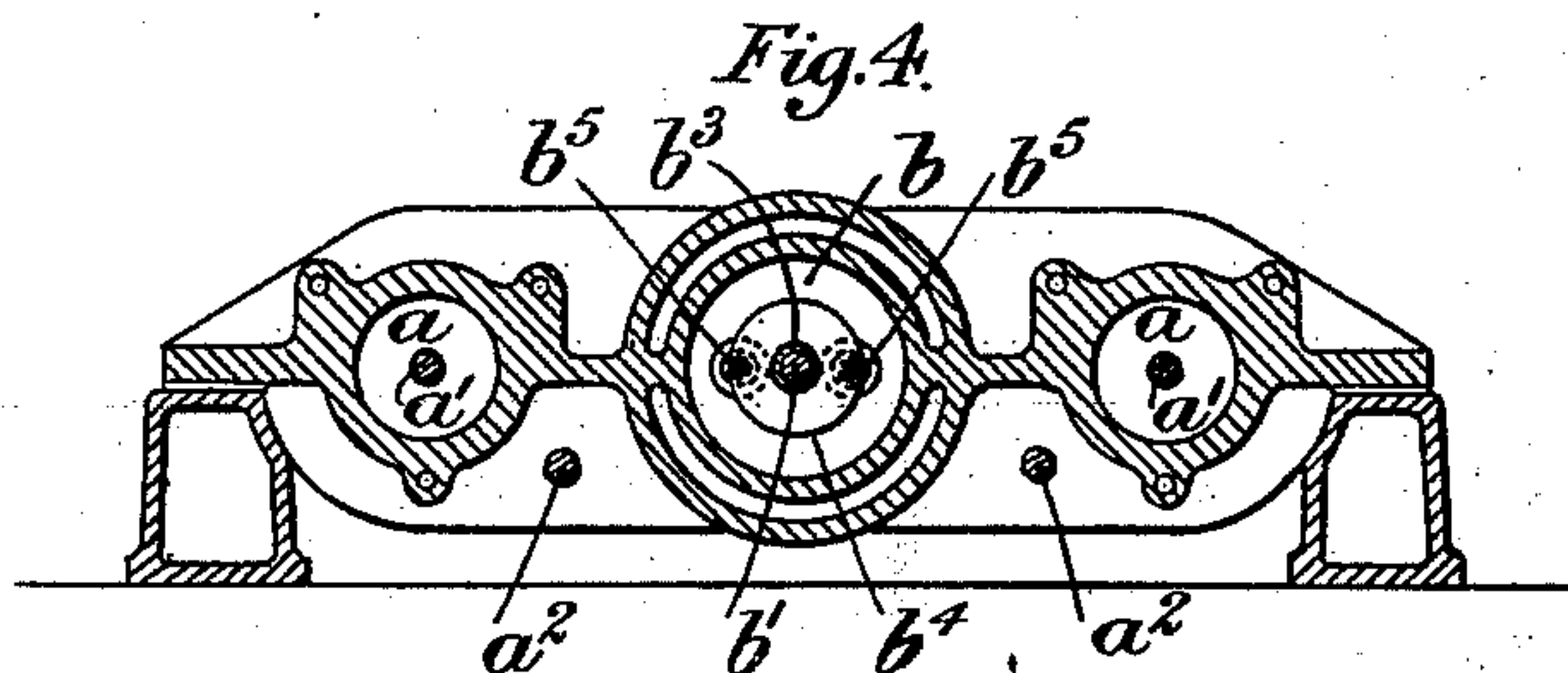
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4 Sheets—Sheet 3.



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(No Model.)

4 Sheets—Sheet 4.

Fig. 7.

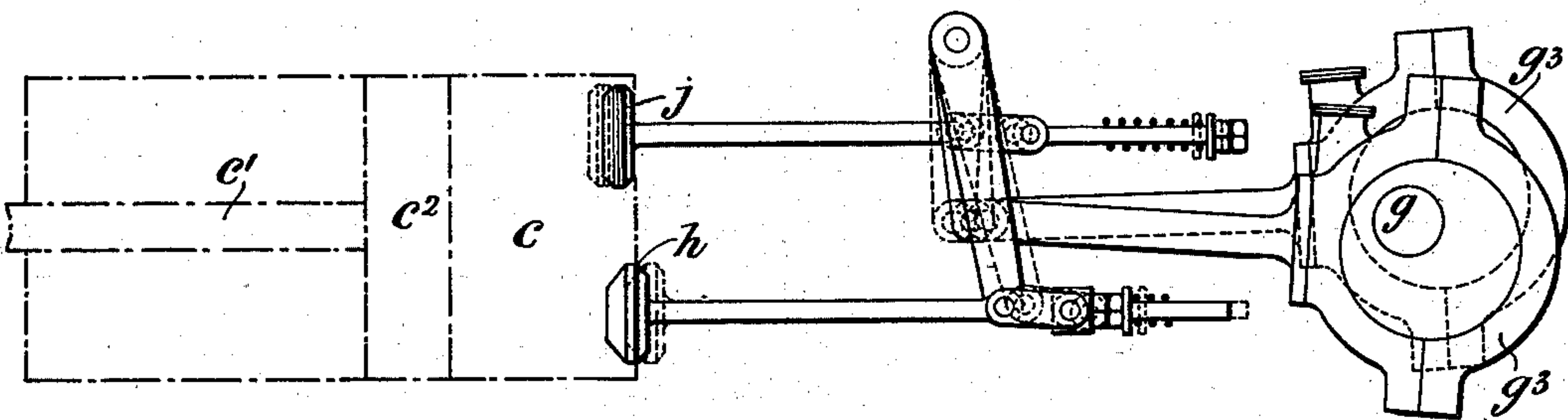
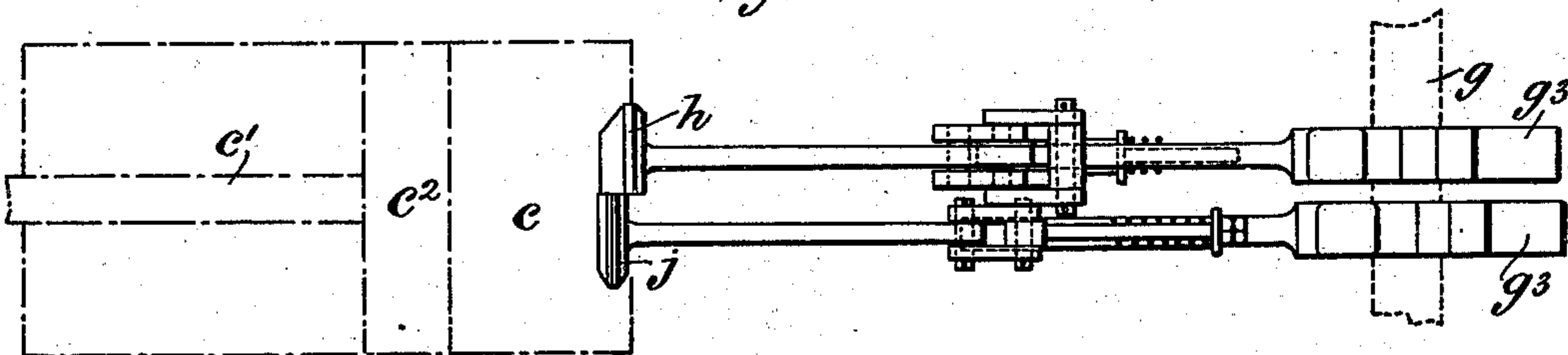


Fig. 8.



Witnesses.

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UNITED STATES PATENT OFFICE.

DANIEL MCGILL, OF WELLINGTON, NEW ZEALAND, AND FREDERICK WILLIAM TANNETT-WALKER, OF LEEDS, ENGLAND.

REFRIGERATING-MACHINE.

SPECIFICATION forming part of Letters Patent No. 654,789, dated July 31, 1900.

Application filed January 31, 1899. Serial No. 704,006. (No model.)

To all whom it may concern:

Be it known that we, DANIEL MCGILL, engineer, residing at Hutt road, Petone, Wellington, New Zealand, and FREDERICK WILLIAM TANNETT-WALKER, engineer, residing at Hunslet, Leeds, in the county of York, England, subjects of the Queen of Great Britain, have invented certain new and useful Improvements in Refrigerating-Machines, of which the following is a specification.

This invention relates to machines in which air (or other gas) is compressed and cooled and then expanded while doing work.

According to this invention the work of the power-cylinders and of the air-expansion cylinder are utilized and more uniformly applied for effecting the work of compression, by means provided for storing power, the arrangement being such that gas is compressed in the compression-cylinder during the return stroke of the power-cylinder by means of the expansion of gas in the expansion-cylinder aided by the stored power. In refrigerating-machines also as usually constructed the suction and exhaust valves through which the air is admitted into the compression-cylinder and expelled from it into the compressed-air reservoir are spring-loaded valves, the result being that during the suction the pressure in the cylinder is less than that of the atmosphere, while during the delivery the pressure in the cylinder is greater than that in the reservoir. According to this invention we obviate the losses resulting from such arrangements by opening and closing the valves at the proper times, not by the air-pressure, but positively by some moving part of the machinery. In order also to avoid loss of cold between the expansion-cylinder and the storage-chamber, we mix the expanded and extremely cold air from that cylinder with the moderately-cold incoming air from the compressed-air cooler or from the storage-chamber, or from both. The arrangement we employ is as follows: The compression and expansion cylinders are single acting and are mounted in a line with each other, their piston-rods being fixed to a cross-head between them. The motive power is applied to the cross-head by a single-acting steam or other cylinder or a pair of single-acting cylinders,

one high and one low, one on each side of the compression-cylinder and working together, or in the case of gas-engines giving only one impulse for each two revolutions the cylinders work alternately. On one side, and preferably on each side of the expansion-cylinder, is a hydraulic cylinder always in connection with an accumulator and having its piston rod or ram fixed to the cross-head. During the outstroke of the power-cylinder air is drawn into the compression-cylinder, expanded and cooled air passes from one side to the other of the piston of the expansion-cylinder, and water is forced into the accumulator. The return stroke is performed by the expansion of compressed and cooled air in the expansion-cylinder and by the pressure of the water in the accumulator acting on the pistons of the hydraulic cylinders. During the return stroke air is compressed in the compression-cylinder (and toward the end of the stroke expelled into the usual cooling and drying apparatus) and expanded air is expelled from the expansion-cylinder. The compressed air coming from the cooling and drying apparatus enters the expansion-cylinder through a hollow casing or jacket surrounding it, so that the incoming air is partially cooled by the cold walls of the cylinder, and the loss of cold by conduction is considerably diminished. The expanded and extremely cold air issuing from the expansion-cylinder is mixed with moderately-cold air drawn from the refrigerating-chamber, and the mixture is led back to the refrigerating-chamber. By this means the great loss of cold which results from leading the extremely-cold air through the connecting-pipes is considerably diminished. We prefer to do this by making the expansion-cylinder larger than is usual and with an earlier cut-off, the formation of a partial vacuum toward the end of the stroke being prevented by opening a communication with the refrigerating-chamber, from which moderately-cold air is therefore now pumped. During the return stroke the mixture of extremely-cold air and moderately-cold air is expelled back into the refrigerating-chamber.

The delivery-valve from the compression-cylinder and the admission-valves to the expansion-cylinder are lift-valves, or, it may

be, rotary disk valves in the cylinder-covers. These valves are worked by suitable gearing from a lay-shaft, and when gas-engines are employed this may conveniently be the valve-shaft of the engine. The suction-valves to the compression-cylinder and the exhaust-valve from the expansion-cylinder are similar lift or disk valves in the pistons. These valves are worked by either sleeves on the piston-rods or rods passing along inside the piston-rods, and the ends of these sleeves or rods are connected by suitable gearing to a rocking shaft in the cross-head, whose ends are fixed to connecting-rods working on cranks on the fly-wheel shaft.

Figure 1 is a diagrammatic plan of a refrigerating plant arranged according to this invention. Fig. 2 is a sectional plan of the engines and pumps, and Fig. 3 is a vertical section on the line 3 3, Fig. 2. Figs. 4, 5, and 6 are local sections on the lines 4 4, 5 5, and 6 6, Figs. 2 and 3, most of the parts behind the planes of section being omitted. Figs. 7 and 8 are an elevation and plan to a larger scale of the gear working the admission-valves to the expansion-cylinder.

a a are the cylinders of two single-acting gas-engines of the Otto type, each giving an explosion at every other out (or left to right) stroke of their pistons and arranged to act alternately. a' a' are their piston-rods, and a^2 a^2 the shafts working their valves. One of these shafts is driven in the ordinary way from the crank-shaft and drives the other by bevel-gear and a cross-shaft a^3 . As these engines are of an ordinary and very well-known type it is unnecessary to show or describe them in detail.

b is the compression-cylinder; c , the expansion-cylinder; b' c' , their piston-rods, and b^2 c^2 their pistons.

d indicates hydraulic cylinders, and d' their rams. The right-hand ends of these cylinders are always in communication by pipes d^2 with an accumulator e , Fig. 1.

The rods a' b' c' d' are all fixed to a cross-head f , which is connected by rods f' to cranks g' on the crank-shaft g , on which is the fly-wheel g^2 . The cross-head f has fixed to it bearings, in which works a rocking shaft f^2 . f^3 is an arm fixed to the shaft f^2 and connected by a link f^4 to one of the connecting-rods f' .

f^5 is a double arm fixed to the shaft f^2 and connected by links f^6 f^7 to sleeves b^3 c^3 , free to move to and fro on the piston-rods b' c' of the compression and expansion cylinders. These sleeves carry arms or disks b^4 c^4 , which at the proper times come against the stems of the valves b^5 c^5 in the pistons b^2 c^2 and, compressing the springs b^6 c^6 , open the valves. By placing the valves in the pistons and operating them as above described several important advantages are gained. The clearance-spaces are reduced to a minimum, the valves can be quickly and widely opened at exactly the proper times, and the valves be-

ing positively opened and not by the pressure of the air, as is usual, do not act as reducing-valves, the pressure on both sides of them when open being the same. It will be obvious that the movement of the connecting-rod can be communicated to the valves in various ways. Thus the rod f' and shaft f^2 might be connected by bevel or other gear instead of by a link. The valves also might rotate instead of lifting, having radial ports, (there being corresponding ports in the pistons,) and be operated by bevel or other gear from the shaft f^2 .

b^7 is a valve in the end of the cylinder b , and b^8 is its spring. It is operated by a cam a^4 on the shaft a^3 .

h and j are a pair of valves in the end of the cylinder c . They are operated by a pair of eccentrics g^3 on the crank-shaft g . The cylinder c is jacketed, and the jacket is divided into two chambers h' and j' by a partition k , as shown in Figs. 5 and 6. The valves h and j put these chambers, respectively, into communication with the inside of the cylinder.

One end of the cylinder b is connected by a pipe l to a refrigerating or cold-storage chamber m , Fig. 1, and the other end is connected by a pipe n to a cooling and drying apparatus o , of ordinary construction. The latter is connected by a pipe p to the chamber h' of the jacket of the cylinder c . The chamber j' is connected by the pipe r to the storage-chamber m , and the latter is also connected by the pipe q to the other end of the cylinder c , Figs. 1 and 2.

The action of the apparatus is as follows: On an explosion taking place in one of the cylinders a the cross-head f is moved from left to right, forcing water from the cylinders d into the accumulator e , so storing power. During the whole of this stroke the valves b^7 , h , and j are closed, while the valves b^5 c^5 are open, so that the air in the cylinders b and c passes through the pistons b^2 c^2 from one side to the other of them. At the end of the stroke the valves b^5 c^5 close and the valve h opens, admitting compressed air from the cooling and drying apparatus o to the cylinder c , and the pressure of this, together with that of the water in the accumulator e , forces the cross-head back again from right to left. During the whole of the return stroke the valves b^5 and c^5 are closed. b^7 is closed at the commencement, but when the air is sufficiently compressed in the left-hand end of the cylinder b it is opened and the compressed air is forced by the pipe n into the cooler o . During the whole of the return stroke air is drawn by the pipe l from the chamber m into the right-hand end of the cylinder b . When the first portion—say one-third—of the return stroke has been completed, the valve h closes and the air in the right-hand end of the cylinder c expands. This cylinder is so proportioned and the timing of the valves so regulated that if no more air were admitted there

would be a partial vacuum at the end of the stroke; but after a time—say two-thirds of the return stroke—the valve *j* opens, and the cylinder *c* then acts as a pump, drawing air from the chamber *m* by the pipe *r*, and this air, which is only moderately cold, mixing with the extremely-cold expanded air in the cylinder *c*, raises its temperature, so reducing loss of cold in the pipe *q*, leading back to the chamber *m*. It will be observed that during the time, or most of it, when the cylinder *c* is acting as a pump the valve *b'* is open and less power is required to move the cross-head.

In cases where it is desired to mix a large proportion of moderately-cold air with the extremely-cold expanded air the above-described arrangement is replaced or supplemented by a pump or fan drawing air from the chamber *m* and delivering it to the pipe *r* at or near to the cylinder *c*.

What we claim is—

1. The combination of a single-acting compression-cylinder closed at both ends by cylinder-heads, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder closed at both ends by cylinder-heads receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, and connections between the three pistons.

2. The combination of a single-acting compression-cylinder, its piston and delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, its piston, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, its piston and admission and delivery valves, means for storing the energy of the outstroke of the power-cylinder, and connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, whereby the energy of the stored power is applied for the instroke of the piston of the compression-cylinder.

3. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power from the outstroke of the single-acting power-cylinder, and connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously.

4. The combination of a single-acting com-

pression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, and connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously.

5. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, means for storing power, and connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously.

6. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, and connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously.

7. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, and means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders.

8. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and pis-

ton, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, and means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders.

9. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, and a hollow jacket to the expansion-cylinder supplied with gas from the cooler and from which the admission-valve leads.

10. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, and a hollow jacket to the expansion-cylinder supplied with gas from the cooler and from which the admission-valve leads.

11. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place

simultaneously, and a hollow jacket to the expansion-cylinder supplied with gas from the cooler and from which the admission-valve leads.

12. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, and a hollow jacket to the expansion-cylinder supplied with gas from the cooler and from which the admission-valve leads.

13. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, and a hollow jacket to the expansion-cylinder supplied with gas from the cooler and from which the admission-valve leads.

14. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, and a hollow jacket to the expansion-cylinder supplied with gas from the cooler and from which the admission-valve leads.

plied with gas from the cooler and from which the admission-valve leads.

15. The combination of a single-acting compression-cylinder, a piston in it, means for
5 actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, an expansion-cylinder receiving compressed and cooled gas from the cooler,
10 a piston in it connected to the piston of the compression-cylinder, admission and delivery valves to it, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-
15 cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second
20 compartment, and means for opening the latter valve toward the end of the outstroke.

16. The combination of a compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves, a cooler
25 receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder
30 end and piston, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second
35 compartment, and means for opening the latter valve toward the end of the outstroke.
40

17. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction
45 valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder
50 end and piston, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading
55 from the second compartment, and means for opening the latter valve toward the end of the outstroke.
60

18. The combination of a single-acting compression-cylinder, a piston in it, delivery and
65 suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-

cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, 70 admission and delivery valves in the cylinder end and piston, connections between the three pistons, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading 80 from the second compartment, and means for opening the latter valve toward the end of the outstroke.

19. The combination of a single-acting compression-cylinder, a piston in it, delivery and 85 suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and 90 compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and 95 power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with 100 gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second 105 compartment, and means for opening the latter valve toward the end of the outstroke.

20. The combination of a single-acting compression-cylinder, a piston in it, delivery and 110 suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, 115 admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that 120 the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow 125 jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission- 130 valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

21. The combination of a single-acting com-

pression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

22. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

23. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, an expansion-cylinder receiving compressed and cooled gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves to it, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valve in the piston of the compression-cylinder, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admis-

sion-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

24. The combination of a compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder end and piston, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valve in the piston of the expansion-cylinder, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

25. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder end and piston, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

26. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and

piston, connections between the three pistons, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

27. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

28. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for work-

ing the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

29. The combination of a compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, an expansion-cylinder receiving compressed and cooled gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves to it, a refrigerating-chamber receiving gas from the delivery-valve of the expansion-cylinder, a hollow jacket to the expansion-cylinder divided into two compartments, supplied with gas respectively from the cooler and the refrigerating-chamber, the admission-valve leading from the first compartment, a second admission-valve leading from the second compartment, and means for opening the latter valve toward the end of the outstroke.

30. The combination of a compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, an expansion-cylinder receiving compressed and cooled gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves to it, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

31. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, an expansion-cylinder receiving compressed and cooled gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves to it, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

32. The combination of a compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder

end and piston, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

33. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder end and piston, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

34. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, connections between the three pistons, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

35. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

36. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections

between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

37. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

38. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves to it, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

39. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, an expansion-cylinder receiving compressed and cooled gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves to it, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valve in the piston of the compression-cylinder, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

40. The combination of a compression-cylinder, a piston in it, means for actuating the

piston, delivery and suction valves, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder end and piston, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valve in the piston of the expansion-cylinder, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

41. The combination of a single-acting compression-cylinder, a piston in it, means for actuating the piston, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it connected to the piston of the compression-cylinder, admission and delivery valves in the cylinder end and piston, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

42. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, connections between the three pistons, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber.

panded in the expansion-cylinder with gas drawn from the refrigerating-chamber. 60

43. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, means for storing power, connections between the three pistons such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber. 70

44. The combination of a single-acting compression-cylinder, a piston in it, delivery and suction valves in the cylinder end and piston, a cooler receiving compressed gas from the compression-cylinder, a single-acting power-cylinder, a piston in it, a single-acting expansion-cylinder receiving cooled and compressed gas from the cooler, a piston in it, admission and delivery valves in the cylinder end and piston, an accumulator, a hydraulic cylinder in constant communication with it, a ram in the cylinder, connections between the three pistons and ram such that the outstroke of the compression and power pistons and the instroke of the expansion-piston take place simultaneously, a crank-shaft, a crank on it, a cross-head, a rocking shaft on the cross-head, a connecting-rod pivoted to the crank and cross-head actuating the rocking shaft, means actuated by the rocking shaft for working the valves in the pistons of the compression and expansion cylinders, a refrigerating-chamber receiving gas from the expansion-cylinder, and means for mixing the gas expanded in the expansion-cylinder with gas drawn from the refrigerating-chamber. 80

DANIEL MCGILL.

FREDERICK WILLIAM TANNETT-WALKER.

Witnesses:

ROBERT B. RANSFORD,
ARTHUR CARP WALL.