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STRAIGHT AIR BRAKE EQUIPMENT.

By J. B. PARHAM, Stud. Can. Soc. C. E.

(To be read before Electrical Section, October 22, 1908.)

The air brake has, for many reasons, come to be regarded as an essential part of the equipment of modern high speed electric cars. Among the more important may be mentioned safety, saving in time, and economy of operation.

Steam roads adopted air brakes because trains could be handled more speedily and much time saved, and for these same reasons electric cars are now being operated on faster schedules than formerly, which means an increase on net efficiency of rolling stock. With the present heavy and increasing traffic to be dealt with, air brake equipment has become a necessity.

Statistics covering the last few years show that a reduction in the quantity of power taken from the line is brought about by the use of air brake apparatus. The average difference in the cost of operating an electric car furnished with hand brakes and one fitted with air brakes, on roads running through large cities where frequent stops are necessary, has been proven by actual test to be between 10% and 15%, the figures being based upon current consumption.

The saving of current is due to the fact that the powerful and instantaneous action of the brake renders it possible to leave the brake shoe clear of the wheel, even when newly adjusted, and allows the motorman to run in "full release" except when he has occasion to use the brakes; whereas, with the hand brakes the shoe must not only be adjusted tightly, but within city limits the motorman must keep the brake dragging, in order to stop quickly enough to avoid collisions. It is also evident from the above that in addition to the economy of power there is also a large saving in brake shoes and labour required in keeping them in repair.

On a modern electric car, with the numerous devices now in use, economy of space is an important consideration. The compressor described herein is one of the most compact and self-contained in use. Its simplicity of construction and easy accessibility much reduces the time required for repairs and inspection. The time required to take it apart is very inconsiderable, and with a great number of equipments in service this means a large saving in cost of maintenance.

The general construction of the motor compressor is shown by the assembly drawing, Plate 1. It will be noticed that it is of a two-cylinder inclosed pattern, driven by a series motor mounted directly above the compressor. Each cylinder is furnished with a single acting piston.

The general data of the machine is as follows:

Diameter of cylinder in inches..	5
Length of stroke in inches..	4
Revolutions of crank shaft per minute..	174
Revolutions of armature per minute..	1350
Capacity in cubic feet free air per minute..	16
H. P. at 90 lbs. pressure..	2.6
Amperes of fuses at 550 volts..	6

The speed and capacity quoted is supposed to be attained at a pressure of 90 lbs. to the square inch.

Plate 2 shows the cast iron pump base, which forms a frame in which the shafting and pistons work. The inside contains an oil reservoir supplied from an oil-filling elbow screwed into the tapped hole shown at " B." Another hole at " C " keeps oil at the same level in the gear casing.

The shaft bearing caps are of cast iron, two in number, and are fastened in place by means of four set bolts, similar to one shown on the drawing.

The gear and pinion are made in two parts. Blanks are cast from steel, machined in a lathe, placed on an arbor, and the teeth, cycloidal, cut in a gear-cutting machine. The teeth are cut at 45° to the axis of the wheels, right handed in one case and left handed in the other. In the case of the gear, these two halves are rivetted together by eight ½" soft iron rivets. The hole in the centre is tapered to fit the crank shaft, and a key way cut in it to receive a cotter. The pinion is rivetted together by four rivets of ⅛" Bessemer rod, and the hole tapered and slotted as in the case of the gear.

Noise is almost entirely eliminated, the teeth being cut to mesh with an accuracy that ensures quiet and smooth running, which is a feature of such herring-bone gear.

The number of teeth are in the ratio of 16:124, giving 7.75 revolutions of the armature to one of the crank shaft.

The cylinder head is of cast iron, and is fastened to the cylinder end by eight ½" cap screws, a brown paper gasket being inserted to ensure an air tight joint. The suction and discharge valve ports are at "D" and "E" respectively. The four valves are similar in construction, made in two pieces of wrought iron, one of cylindrical shape closed at one end (which end fits in the valve seat), and the other of flat circular shape brazed into the open end of the cylinder. It will be noticed that no springs are used in connection with these valves, which work independently and by gravity alone. They are ground into their seats, and may be removed at any time by simply unscrewing the brass nuts above them, without disturbing any other part.

The incoming air may come in through the port at "F"; but usually in the case of electric cars, in order to avoid dust interfering with the operation of the pump, the air is filtered through hair at the top of the car and brought down in pipes tapped into the cylinder head below the suction valve. The ports "F" are equipped with a wire screen, and are chiefly used when the compressor is in shop service, where less trouble from dust is encountered.

The crank shaft, pistons, piston rings, connecting rods, and piston pins are all shown on Plate 3.

The crank shaft consists of a steel forging with bearings turned to size. One end is tapered to receive the gear, which is securely fastened in place by a cotter key, washer, nut, and split key. The cotter is 1¾" x ⅜" x $\frac{7}{16}$", and made of machine steel.

The two pistons are of cast iron, machined and ground in a grinding machine to exactly fit the cylinder.

Each of the two piston rings is made in three segments, each segment being in two pieces rivetted together, all of cast iron. These are ground in a similar manner to the pistons, and each ring is put in position in the cylinder with three small spiral springs inserted at holes in each segment placed at "A," which

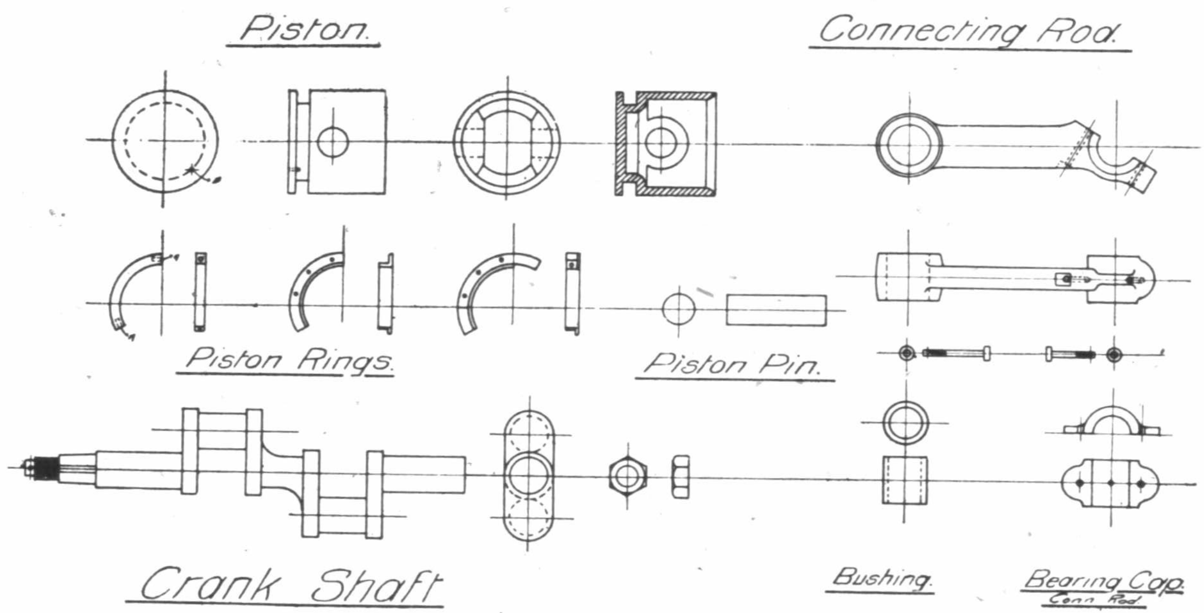

Piston.
Connecting Rod.
Piston Rings.
Piston Pin.
Crank Shaft
Bushing.
Bearing Cap.
Conn. Rod.

Plate 3.

keep the ring tight against the cylinder. A hole $\frac{1}{64}$" in diameter is drilled at "B," and admits air under the rings during the compression stroke, thus furnishing air packing.

The two connecting rods are of cast iron. One end of each of these is furnished with a brass bushing forced in, and is secured to the piston by means of a piston pin. The other end is fastened to the crank shaft by a bearing cap of brass held in position by two wrought iron bolts, the nuts of which are secured by split keys. Before assembling the pump the cap is bolted in place with a few tin liners between it and the connecting rod, and the bearing hole reamed out to size. One or more of these liners can be removed when assembling to give a good fit.

The two piston pins are of steel forging, each turned and ground with a taper about 4 or 5 thousandths of an inch over its length, and driven home with no fastening of any kind. No trouble has been experienced by its working loose.

The motor base, field frame, and bearing cap are shown on Plate 4.

The motor base is made of cast steel, contains the armature bearing housings, forms part of the magnetic circuit of the motor, and is fastened by $\frac{1}{2}$" cap screws to the pump base. The bearing housings are fitted with oil wells, the oil well in the front bearing housing draining into the reservoir below through a hole drilled at "A." The front bearing cap is held in place by two $\frac{5}{8}$" cap screws, and carries the brush holder yoke. The rear bearing cap is fastened down by two long cap screws, which go down through the motor base and thread into holes in the pump base below. Hinges for the doors are at "J" and "K." The two holes at "L" are for vulcanite bushings, through which the motor leads are run.

The field frame is also of cast steel, forming the remaining half of the motor magnetic circuit, secured to the motor base by three $\frac{1}{2}$" cap screws at "B," "C," and "D," and two dowel pins at "E" and "F."

The clamp bolts are three in number, of wrought iron, and serve to hold the field coils in place. Door hinges are shown at "G" and "H."

The doors hinge on to the motor base and field frame, and are designed to protect the motor from dust and dirt. The other end is protected by the field frame fitting down tightly on to the motor base, leaving only a hole for the armature shaft. The doors fit tightly together, and are fastened with a bolt provided with a wing nut. The doors are of malleable iron.

The gear case is made of cast iron, and fastened to the pump base and motor base by means of ten cap screws, a leather gasket being inserted to make the joint air tight. Two holes, tapped and fitted with plugs, serve to drain away any superfluous oil, leaving only the proper quantity to lubricate the machine.

The brush holder yoke is of cast iron, and is fastened to the front bearing cap by a quarter-inch screw through a slot, which is for the purpose of giving the proper backward lead to the brushes.

The two brush holders are made of brass throughout. The main body is bolted to the yoke through a vulcanite bushing, and carries a lever arm. A small tension block is attached to this arm, bearing on the brush, which is of carbon, the necessary tension being supplied by the spiral spring. The leads are sweated into the lugs, one on each holder.

The shaft of the armature is made of machine steel, one end tapered to receive the pinion, which is held in place by a cotter key, washer nut, and split key. The part of the shaft adjoining the pinion fits into the rear bearing; next is placed an oil guard of cast iron; and next to that the two end plates, between which are the laminations, 239 in number, all held together by a wrought iron nut. Adjoining the nut is the commutator sleeve and commutator wedge holding the commutator segments, 105 in number. The segments are insulated from the sleeve and wedge and each other by mica. The wedge goes on to the sleeve, which is threaded to receive a disc screwed tightly upon the wedge and secured to it by four ¼" machine screws to obviate any possibility of its unscrewing. An oil thrower is firmly fastened to the shaft by means of a taper and forced fit. The remainder of the shaft fits into the front bearing. The bearings are made of brass, and each is equipped with an oil ring.

The laminations are of soft sheet iron .015" thick, and punched out on a machine. The armature shaft is furnished with a longitudinal slot, and the laminations key into this slot. The slots are 53 in number, [illegible]" deep and .17" wide. Each lamination is of 7" outside diameter, and is varnished for insulation purposes to reduce eddy current losses as much as possible.

In the armature winding there are 53 slots and 106 coils. There being but 105 commutator bars, 105 coils are connected up, the remaining coil being idle and put in to complete the winding. Each coil is form wound and taped, consisting of 10 coils of No. 21 B. & S. gauge, double cotton-covered wire. There are 4 composite conductors in each slot, and as each one contains 10 wires, the total number of conductors in each slot is 40, making 2120 in the whole winding, or 2100 leaving out the idle conductors, the terminals of the coil to which they belong being cut off short and taped. There being two paths for the current, 1050 conductors are in series. The coils are held in place by a few turns of wire around the armature at each end and at the centre of the core.

Field Winding.—Two of the four poles of the motor are wound, each winding consisting of about 735 turns of No. 14, B. & S. gauge, single cotton copper wire. Each coil is form wound and covered with tape, is slipped over the pole, and held in place by the clamp bolts.

Plate 5 shows the general arrangement of the apparatus.

1. Electric motor-driven air compressor just described in detail.
2. Box to cover it from dust, etc.
3. Cage for supporting box and compressor under a car.
4. Insulating coupling to obviate any ground through the piping.
5. Seamless cold drawn steel reservoir for storage of the compressed air where its pressure is kept within the proper limits by means of an automatic governor regulating the supply. This for an ordinary car is of 392 cubic feet free air capacity, and the pressure is not allowed to rise above 90 lbs. per square inch nor fall below 80 lbs. It is fitted with a safety valve set to blow off at 90 lbs. or 100 lbs.
6. Automatic electric governor. (See Plate 6.)

   This governor, which stops and starts the motor, consists of an ordinary pressure gauge made of brass pipe of elliptical section bent into an arc of a circle. When the pressure comes on, the ellipse tends to elongate along the minor axis, thus increasing the radius of the circle of which the pipe is an arc and giving a sensible movement to the end of the pipe, which motion is magnified and transmitted to the dial hand by means of a lever, ratchet, and pinion mechanism.

   The operation of the governor is very simple. When a carbon block on the dial hand comes into contact with a carbon stud, marked "start," at the point of minimum pressure on the dial, it allows a current to flow through magnet coil No. 1 from the trolley to ground, attracting the plunger 3 and making contacts at 4, thus completing a circuit from trolley to motor to ground. (Plate 5.) When the pressure reaches the maximum the hand strikes the stud, marked "stop," connection coil No. 2 to ground, impelling the plunger in the opposite direction and breaking the circuit through the motor. To avoid arcing at the contacts 4, and thus corroding the copper of which they are made, a blow-out coil, consisting of about 200 turns of No. 15 wire, B. & S. gauge, is placed in series with the main circuit. This coil energizes a magnet causing a flux across the contacts. In case an arc is formed upon the cessation of the current it is urged across the field of the magnet in the same manner as an armature conductor is driven across the field which

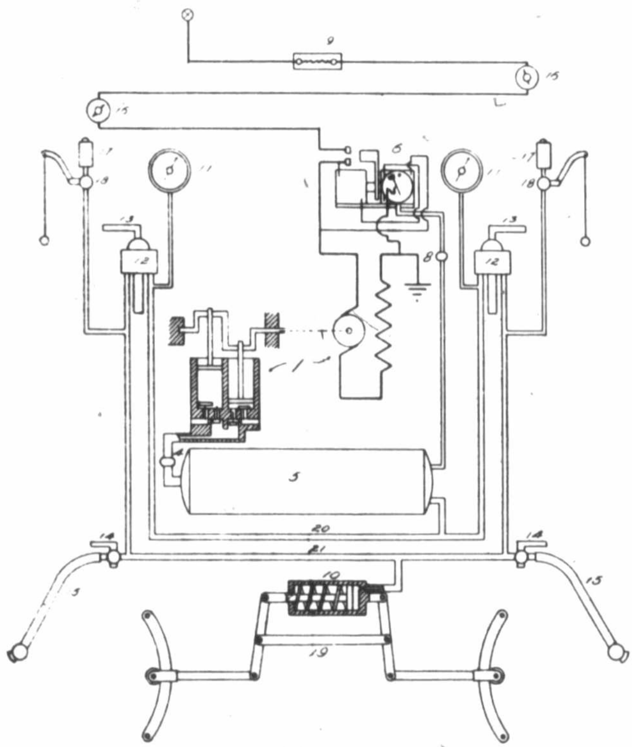


Plate 5.

is applied to it. By this means the arc is drawn out and broken instantly.

The coils 1 and 2 are wound in two halves each, one half in a right-handed, the other in a left-handed manner, the idea being to exert a central pull on the plunger; otherwise, it would strike the end of the coil a heavy blow. Each coil is wound with about 70,000 turns in all of No. 33 wire, B. & S.

Automatic Electric Governor.

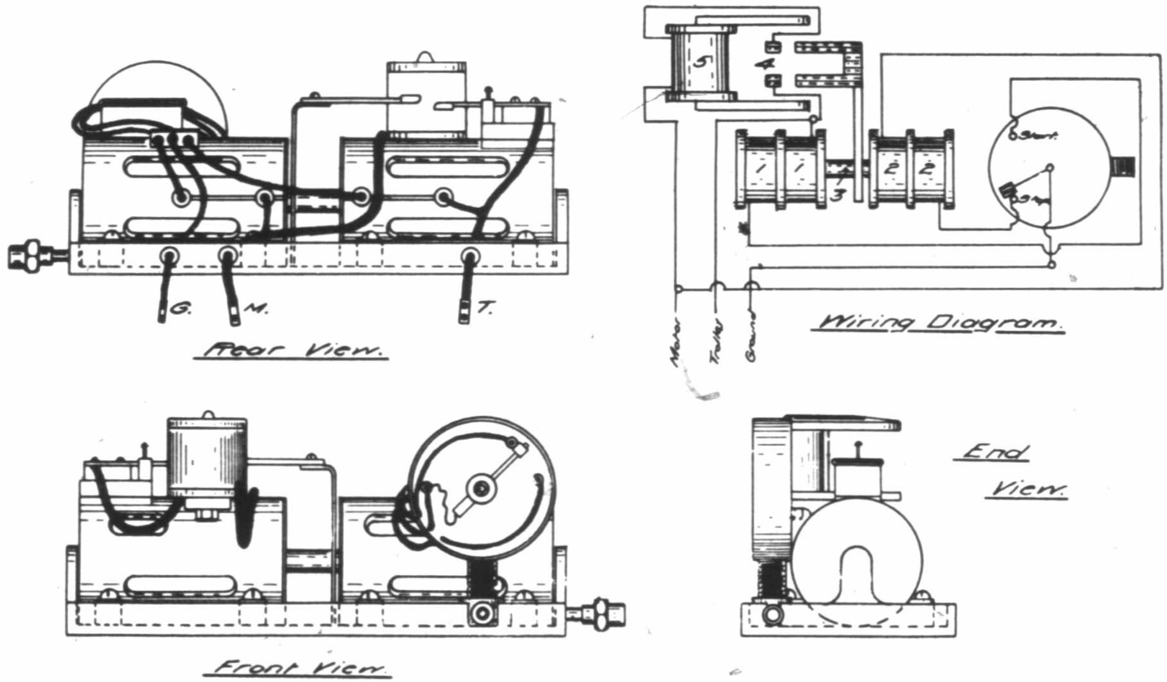
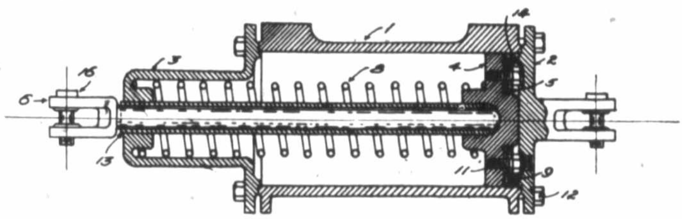


Plate 6.

gauge, giving a very high resistance and practically eliminating all possibility of burning out.

7. Cover for governor, of sheet iron.
8. Another insulating coupling.
9. Non-arcing inclosed fuse to protect the compressor motor.
10. Brake cylinder. When the brakes need to be operated, air from the reservoir is admitted, through the engineer's valve, to the brake cylinder, which applies pressure to the shoes and thence to the wheels by means of a suitable lever mechanism.

The cylinder is provided with a loose piston rod (Plate 7), so arranged that when the hand brakes, and not the air



Brake Cylinder.

Plate 7.

brakes, are used the loose piston rod only is moved. The pipe in which it slides is fixed to the piston of the brake cylinder, which is held in release position by a spring.

The size of cylinder depends on the weight of the car on which it is to be used. These figures allow for the load which may be on the car.

Weight of Car.	Size of Cylinder.
50,000 to 70,000 pounds..	10-in. dia. by 12-in. stroke.
30,000 to 50,000 pounds..	8-in. dia. by 12-in. stroke
20,000 to 30,000 pounds..	7-in. dia. by 12-in. stroke
15,000 to 20,000 pounds..	6-in. dia. by 12-in. stroke

11. Air gauge mounted in such a position as to be easily observed by the motorman.
12. Engineer's brake valve, by means of which air is admitted from the reservoir to the brake cylinder and thence discharged to the atmosphere. Two types of this are made, rotary plug or slide valve. Both are illustrated in Plate 8.
13. Handle for engineer's valve.
14. Cut-out cock for trailer connection.
15. Hose and coupling for trailer.
16. Snap switch.
17. Whistle.
18. Independent valve for whistle.
19. Brake lever rigging.
20, 21. Pipe and fittings. The piping consists of two sections: The reservoir pipe, connecting the reservoir with the engineer's valve, and the train pipe leading from that valve, which runs the entire length of the train or car, hose couplings being used between cars. A stop cock at each end prevents the escape of air, when the opening is exposed.

All of these pipes are ¾".

Rotary Valve Parts.

1. Base.
2. Seat.
3. Valve top.
4. Valve.
5. Valve stem.
6. Valve handle.
7. Union nut.
8. Ferrule.
9. Pipe gasket.
10. Seat gasket.
11. Latch.
12. Latch spring.
13. Stem spring.
14. Tee bolt and nut.
16. Guard.
17. Screw for oil hole.
18. Screw for guard.

Slide Valve Parts.

7. Union nut.
8. Ferrule.
9. Pipe gasket.
11. Latch.
12. Latch spring.
13. Stem spring.
14. Tee bolt and nut.
16. Guard.
17. Screw for oil hole.
18. Screw for guard.

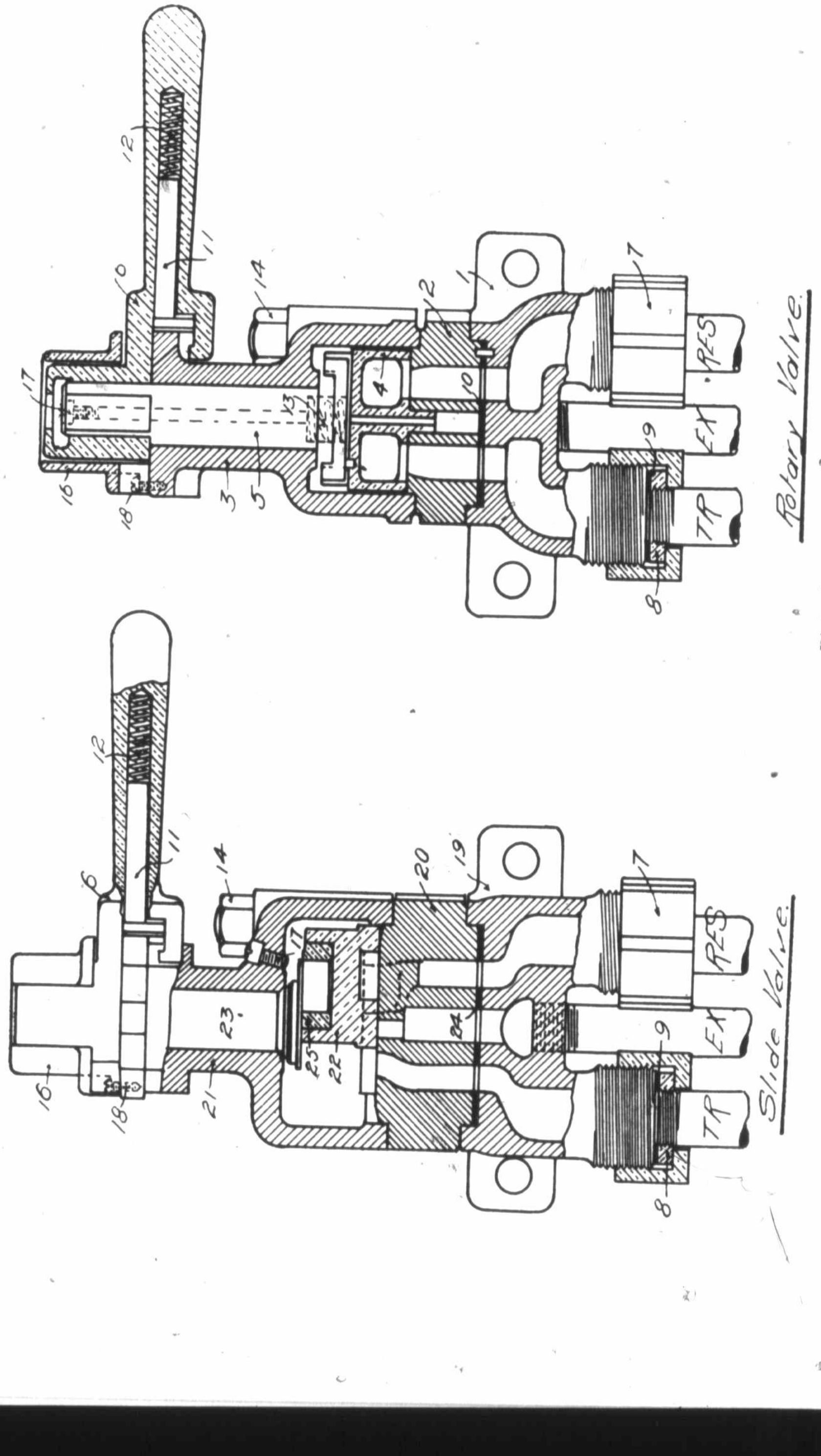


Plate 8.

19. Base.
20. Seat.
21. Valve top.
22. Valve.
23. Valve stem.
24. Seat gasket.
25. Auxiliary slide.

Brake Cylinder Parts.

1. Cylinder body.
2. Forked back head.
3. Front head.
4. Piston.
5. Follower.
6. Loose rod.
8. Release spring.
9. Expander spring.
11. Follower stud bolts.
12. Tee bolts.
13. Pipe for loose rod.
14. Packing leather.
15. Rod pin.

Test of Motor-Compressor.

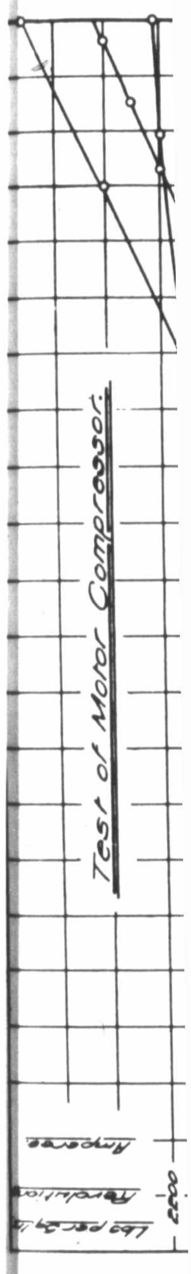
The following test was made on a compressor before being sent out of the shop, and cannot justly be taken to represent its performance after being used for some time. At 550 volts the machine was rated to draw 4.3 ampéres, giving an output of 2.6 H. P., the speed of the motor being 1350 R. P. M.—all this when working at 90 pounds pressure. This rating gives an efficiency of motor and pump equal to 82%, whereas the maximum efficiency under the test was found to be slightly over 51%.

The compressor was connected to a constant potential of 550 volts and allowed to run at no load for some time, a reading of speed and also of current being taken. A stop cock was then turned and the machine put to work to pump up a reservoir, of 392 cubic feet free air capacity, to a pressure of 90 pounds per square inch above atmosphere; observations for pressure, current, and hundreds of revolutions of the armature being taken and the time noted. At the end of 110 seconds a pressure of 90 lbs. was reached. The stop cock leading to the outside air was then slightly opened, just enough to keep the pressure valve on the reservoir reading 90, and the pump was allowed to run against this equivalent pressure of 90 pounds for an hour. At the end of that time the outside temperature of the cylinders was found to be 158° F.; the temperature of the room being 82.5° F.; and the temperature of the yoke, series fields, and armature was 109.5° F., 140.0° F., and 134.5° F. respectively.

RESULTS FROM TEST.

Time, Seconds.	Pressure, Lbs. sq. in.	Current, Amperes.	Revolutions.
0.0	0.0	3.2	0
3.5	—	—	100
7.0	—	—	200
10.0	10.0	3.7	—
10.5	—	—	300
14.5	—	—	400
17.5	20.0	—	—
18.0	—	—	500
22.0	—	—	600
25.5	—	—	700
26.0	30.0	—	—
30.0	—	4.3	800
34.5	—	—	900
37.5	40.0	—	—
38.5	—	—	1000
42.5	—	—	1100
47.5	—	—	1200
50.0	50.0	—	—
52.0	—	—	1300
57.0	—	—	1400
60.5	—	—	1500
62.5	60.0	5.0	—
66.0	—	—	1600
71.0	—	—	1700
76.0	—	—	1800
78.5	70.0	5.3	—
81.0	—	—	1900
86.0	—	—	2000
91.0	—	—	2100
95.0	80.0	—	—
96.5	—	—	2200
99.5	—	5.5	—
102.5	—	—	2300
108.0	—	—	2400
110.0	90.0	5.6	—
113.0	—	—	2500

The observations of pressure, current, and speed taken during the test were then plotted on a time base. (Plate 9.) The tangent of



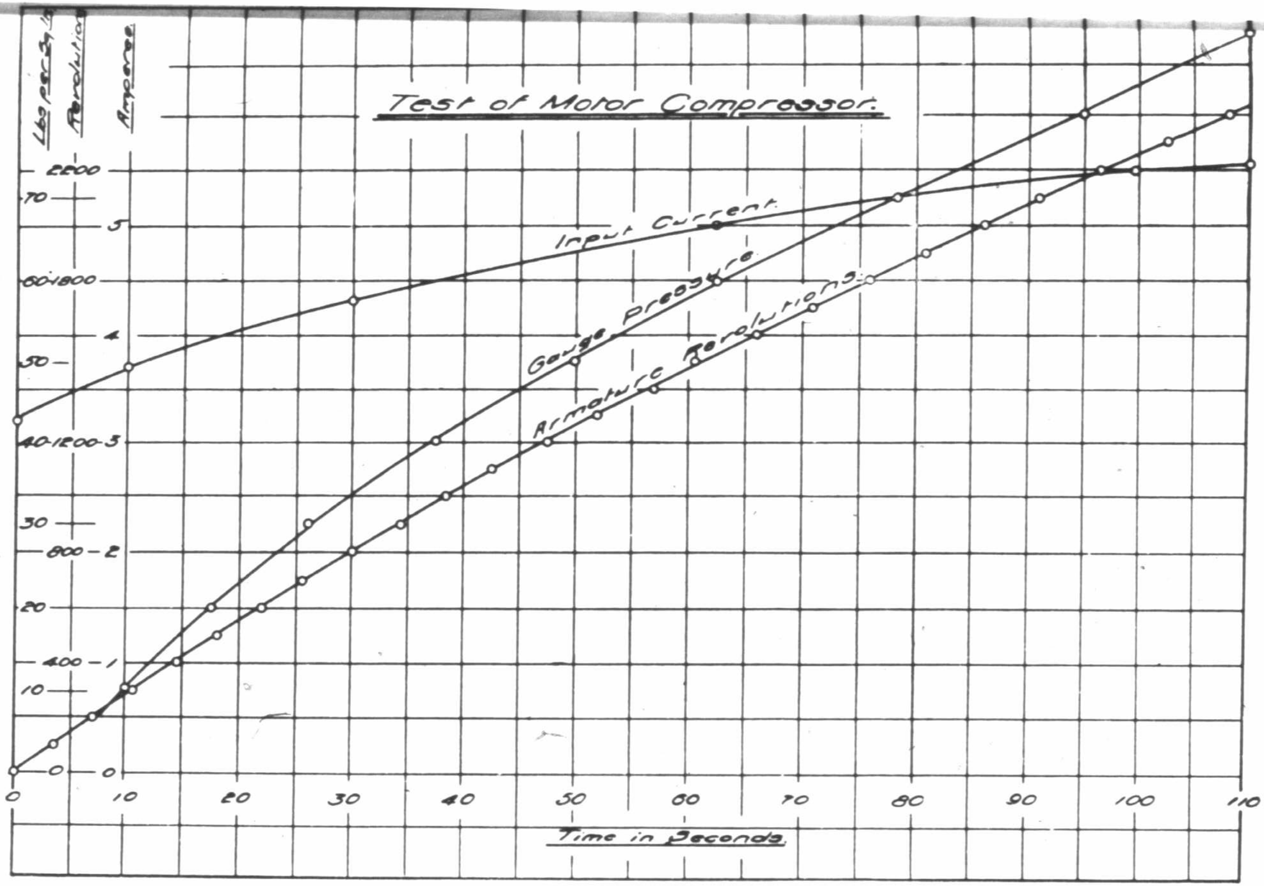

Test of Motor Compressor.
Lbs per Sq In
Revolutions
Amperes
Input Current
Gauge Pressure
Armature Revolutions
Time in Seconds
0
10
20
30
40
50
60
70
80
90
100
110
2200
70
5
60-1800
4
50
40-1200-3
30
800-2
20
400-1
10
0

Plate 9.

the revolution curve at each pressure was then found $\frac{ds}{dt}$, which equals the speed of the motor at that pressure. From this the speed of the shaft was found by dividing by 7.75, and the number of strokes by multiplying by 2.

Gauge Press. Lbs. sq. in.	Volts.	Amperes.	E.H.P.	R.P.M. Arm.	R.P.M. Shaft.	Str. per Min.
0	550	3.2	2.36	1900	245	490
10	550	3.7	2.73	1685	217	434
20	550	4.0	2.95	1550	200	400
30	550	4.3	3.17	1450	187	374
40	550	4.65	3.43	1373	177	354
50	550	4.8	3.54	1312	169	338
60	550	5.05	3.73	1254	162	324
70	550	5.3	3.91	1194	154	308
80	550	5.45	4.02	1134	146	292
90	550	5.6	4.13	1075	139	278

One of the motor leads and the frame of the compressor were placed across a potential of 1500 volts alternating current and the resulting current was nil, showing that the insulation resistance of the machine was satisfactory.

The machine was placed in free connection with the reservoir, and in consequence of leakage through discharge pipe, valves and pistons the pressure fell 1 lb. in 10 minutes.

Taking 1 lb. of air at 1 atmosphere and 521° F. absolute to occupy 13.1 cubic feet, the volume of 1 lb. at 1 atmosphere and 543.5° F. absolute (the temperature of the room) was found to be 13.65 cubic feet.

The volumes V of one cubic foot of air at the end of compression to pressures P was then calculated using formula

$$P_1 V_1^n = P V^n, \ n \text{ being assumed to} = 1.35$$

being a fair estimate for this style of compressor working at high speed.

$$\frac{P}{P_1} = \left(\frac{V_1}{V}\right)^{1.35}$$

$P_1 = 2116$ lbs. per sq. ft. absolute

$V_1 = 13.65$ cu. ft.

$$\log \frac{P}{P_1} = 1.351 \log \frac{V_1}{V}$$

$$.7407 \log \frac{P}{P_1} = \log \frac{V_1}{V}$$

$$\text{antilog } .7407 \log \frac{P}{P_1} = \frac{V_1}{V} = L$$

$$\text{and } V = \frac{V_1}{L} = \frac{13.65}{L} \text{ cu. ft.}$$

There being no means at hand by which to take indicator diagrams, figures for the work done were obtained as follows:

The net work of compression and delivery

$$= \frac{PV - P_1V_1}{.35} + PV - P_1V_1 = 3.857\ PV - 3.857 P_1V_1$$

$= W$ ft. lbs. per pound of air,

V, V_1 being in cu. ft. and P, P_1 in pounds per sq. ft.

RESULTS.

P Lbs. per sq. ft. absolute.	$\log \frac{P}{P_1}$	$.7407 \log \frac{P}{P_1}$	$\frac{V_1}{V}$	V cu. ft.	W ft. lbs.
2116	—	—	—	—	—
3556	.2254	.1670	1.469	9.293	16000
4996	.3731	.2764	1.890	7.223	27800
6436	.4831	.3578	2.279	5.989	37200
7876	.5708	.4228	2.647	5.156	45200
9316	.6437	.4768	2.998	4.554	52100
10756	.7061	.5231	3.335	4.093	58400
12196	.7607	.5635	3.660	3.729	64000
13636	.8092	.5994	3.976	3.434	69100
15076	.8528	.6317	4.283	3.187	73900

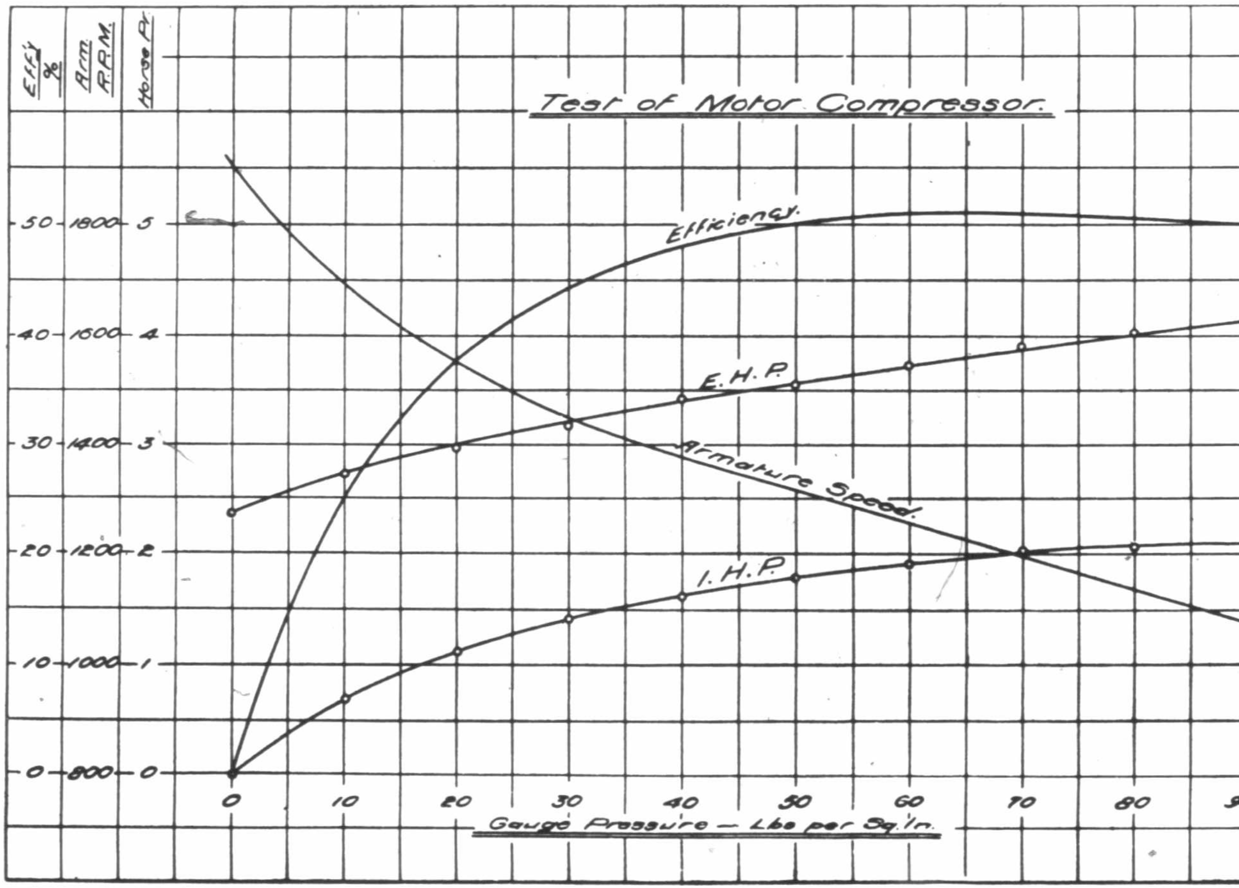
This assumes that air at end of suction stroke was still at the temperature of the room, 543.5° F. absolute, and neglects clearance and leakage. These latter two would tend to decrease net work done; on the other hand the pressure would require to fall slightly below atmosphere before admission could take place and rise slightly above the gauge pressure at end of compression, in order to manipulate the valves, which would tend to increase the net work; so these factors would counterbalance to a great extent.

The capacity in cubic feet of free air per minute was then calculated = volume of cylinder × strokes per minute, and the weight of air compressed per minute found by dividing the product by 13.65. W in the table above was multiplied by this quotient giving the number of foot pounds of work done per minute and hence the I. H. P.

$$\frac{\text{I.H.P.}}{\text{E.H.P.}} = \text{efficiency.}$$

Volume of cylinder = .04547 cu. ft.

Gauge press. lbs. per sq. in.	Strokes, per min.	Cu. ft. free air per min.	Lbs. air per min.	Ft. lbs. work per min.	I.H.P.	Eff. %
0	490	—	—	—	—	—
10	434	19.73	1.446	23130	.699	25.60
20	400	18.19	1.332	37040	1.123	38.10
30	374	17.01	1.246	46350	1.408	44.40
40	354	16.10	1.179	53300	1.615	47.10
50	338	15.37	1.126	58660	1.778	50.25
60	324	14.73	1.079	63030	1.910	51.25
70	308	14.00	1.026	65660	1.990	50.85
80	292	13.28	.973	67220	2.037	50.60
90	278	12.64	.926	68440	2.074	50.25



Test of Motor Compressor.
Eff'y %
Arm. R.P.M.
Horse Pr.
50 - 1800 - 5
40 - 1600 - 4
30 - 1400 - 3
20 - 1200 - 2
10 - 1000 - 1
0 - 800 - 0
Efficiency.
E.H.P.
Armature Speed.
I.H.P.
0
10
20
30
40
50
60
70
80
90
Gauge Pressure — Lbs per Sq. In.

Plate 10.

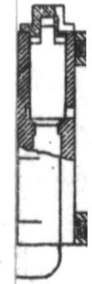
om

550 V

1350

48 S

Scu. F



Motor Air Compressor.

2·6 HP	550 Volts.
4·3 Amps.	1350 R.P.M.
5" Cyl. Dia	348 Strokes per Min.
4" Stroke.	16 cu. Ft. Free Air " ".

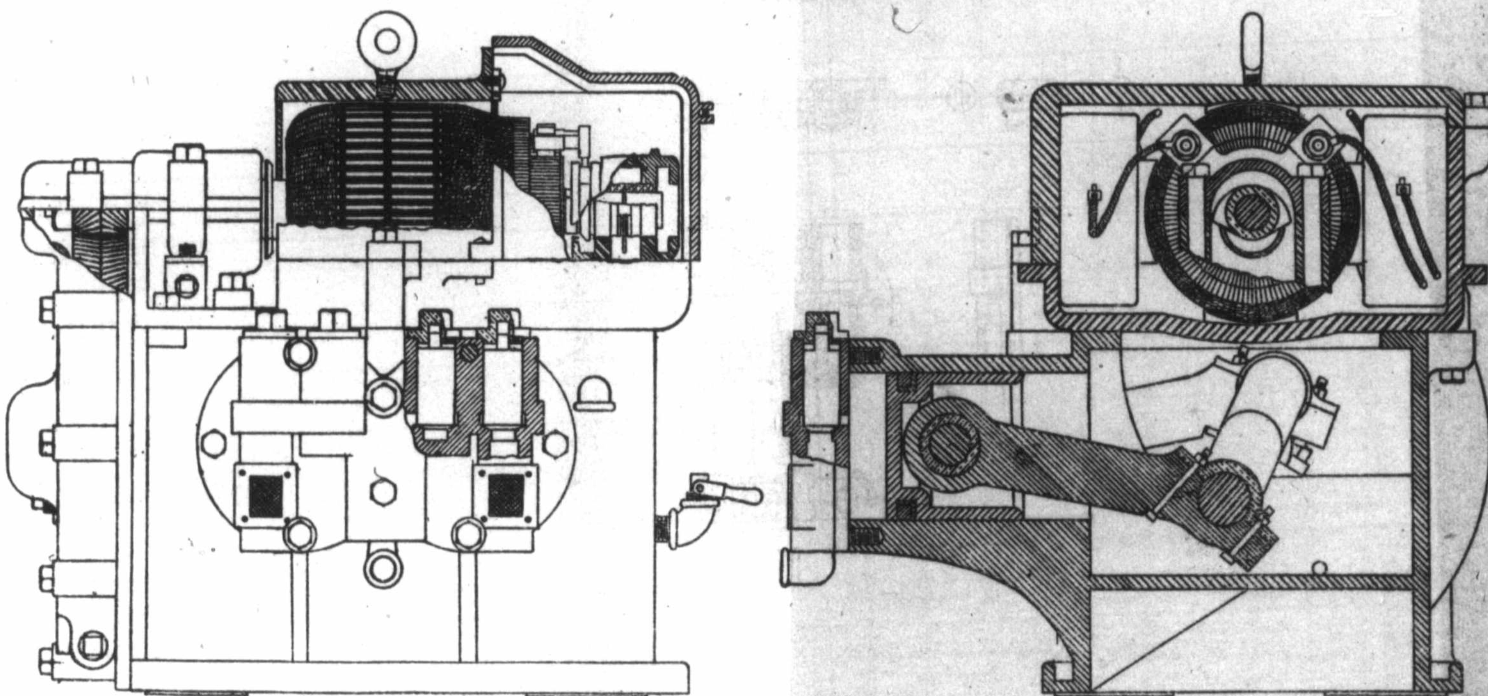


Plate 1.

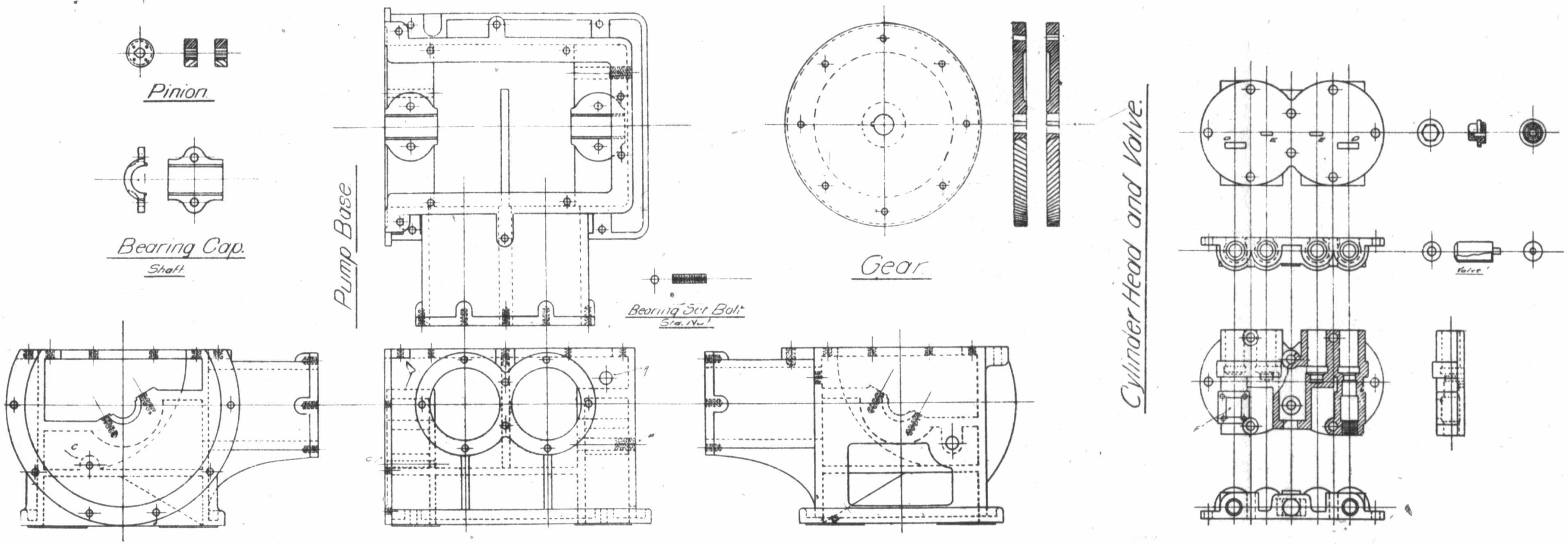

Pinion
Bearing Cap.
Shaft
Pump Base
Bearing Set Bolt
Gear
Cylinder Head and Valve.
Valve

Plate 2.

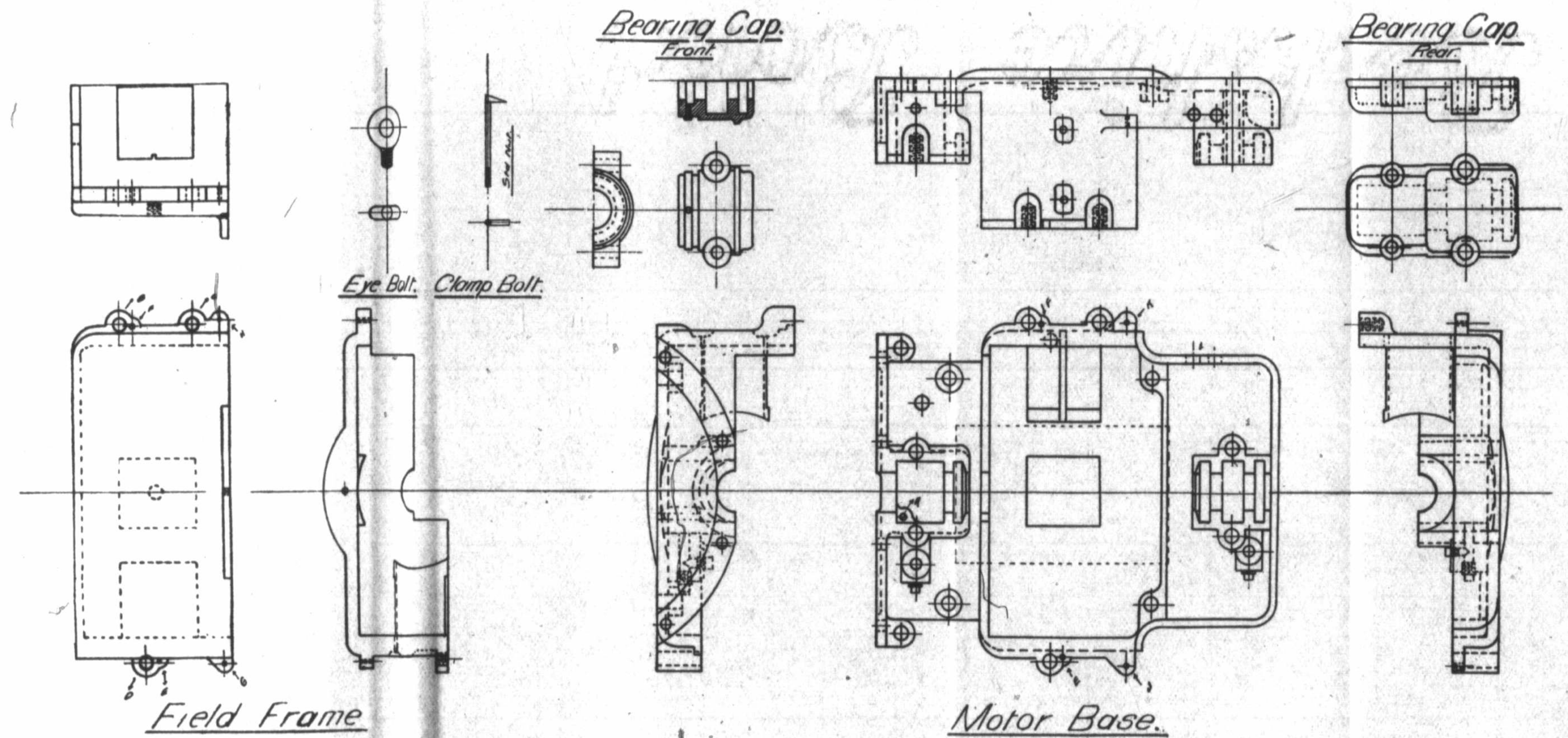

Bearing Cap.
Front.
Bearing Cap.
Rear.
Eye Bolt.
Clamp Bolt.
Field Frame
Motor Base.

Plate 4.