T H E S I S

on

[illegible]

[illegible]

[illegible] C-O-L-L-E-G-E

[illegible]

in

[illegible]

[illegible]

Approved by [illegible]

Professor of Electrical Engineering

[illegible]

T H E S I S

on

R E C T I F I E R S

Submitted to the Faculty

of the

O-R-E-G-O-N A-G-R-I-C-U-L-T-U-R-A-L C-O-L-L-E-G-E

for the degree

of

Bachelor of Science

in

Electrical Engineering

By

Redacted for privacy

and

Redacted for privacy

Approved by Redacted for privacy

Professor of Electrical Engineering

Redacted for privacy

Dean of School of Engineering

June 10, 1911.

Recterfier.

A direct current is a unidrectional current; that is, one that does not change in direction of flow, although it may change in value or amount. Direct currents are produced by voltic cells, dynamos, etc.

A pulsating current is a direct current that consists of distinct and regular impulses.

A continuous current is a steady non-pulsating direct current. Either a pulsating or a continuous current may vary in value: for example, either may be, say, 50 amperes at one moment and may rise to 75 amperes or drop to 25 amperes the next moment, as the load conditions vary. An alternating current is one that periodically reverses in direction, flowing to and fro in a conductor. An alternating current passes through continually recurring series called cycles. The number of cycles per second is called the frequency, and the length of time required to complete one cycle is called a period. Alternating currents are in commercial use at frequencies varing from 25 to 140 cycles.

Frequencies such as 40 to 60 are considered best for lighting purposes.

Nearly all lighting systems use the alternating current, but there are certain kinds of necessities that require the direct current only; such as, storage batteries, types of arc lamps and for electriopating.

There are at present four common methods of converting the alternating current into direct current. These are in order of use, the motor generator set, the rotary converter, mercury vapor rectifier and the Murphy rectifier. A short description of these and connections for the last two will be given.

The motor generator set consists of two separate complete machines and are simply direct connected or place on the same shaft. The motor is of the induction motor type connected to the alternating supply. This is converted into mechanical power which drives the direct current generator. The rotary converter is very much the same as the motor generator set. Instead of two separate armatures there is but one and it is so designed as to carry alternating and direct current. If alternating current is supplied to the armature it will act as a motor and at the same time generate direct current which may be taken off by a commutator and brushes. There is a definite ratio between the voltages in the two curcuits which may be easily predetermined when designing. This is also known as a double current generator because, if it were driven mechanically both alternating and direct current may be taken from the collecter rings and brushes respectively. The smaller apparatus for rectifying current and the one used principally on small loads only is the mercury vapor rectifier and now the Murphy electricity rectifier. These smaller types are transformers of alternating current to direct current and the principles will thoroughly discussed.

The vapor rectifier does not have any rotating parts but consists essentially of a pear shaped glass bulb and containing two positive leads or "anodes" in the upper part is exhausted to as nearly a complete vaccuum as possible and in the lower part is mercury. The positive terminals terminate inside the bulb with the electrodes made of graphite or some conducting substance which will not amalgamate with the mercury and which serves to conduct the current from the external circuit to the vapor inside. The cathode is formed by the mercury in the bottom of the bulb from which the current is conducted to the external circuit by a platinum electrode sealed in the glass. Near this terminal is another small terminal of mercury which is just an auxiliary lead for starting. This is done by tipping the bulb to one side or the other until the mercury bridges across and makes connections with the other mercury which immediately forms an arc and vaporizes the mercury, thus making connections between the positive leads or anodes and cathodes, after this is established the auxiliary is cut out. The positive leads are connected to the terminals of the secondary winding of a transformer and the negative lead is connected, through a reactance coil to the positive side of the load currant. The negative side of the load current is connected to the middle tap of the secondary winding. The rectifier bulb has a peculair property of conducting electicity in one direction only, i.e., from anode to cathode, under ordinary working conditions, thus it may be considered as an electric check valve.

During the period when P, (the letters corresponding to the ones on the diagram) is positive, the valve will allow current to flow from the positive lead P, through the vapor to the negative terminal K. This flow though unidrectional, is very fluctuating and to smooth the effect, reactance is inserted. The explaination of the action of this type of rectifier is very well shown by the action of the simple reciprocating pump. During one half cycle the water may enter at one end of the cylinder and be forced down through the valve leading to K., and during the other half cycle water may enter the opposite end of the cylinder and similiary be forced through K.

This rise and sudden drop of pressure as the piston reverses causes a very fluctuating flow. This is reduced to a steady flow by means of the air chamber similar to the action of the reactance coil in the direct circuit of the rectifier. From this there may be a discrepancy in that the air chamber stores up water under pressure, while the reactance coil does not store up current but builds up a magnet field there by storing up electrical energy electrical energy.

To explain the action of a mercury-vapor converter, reference is first made to Fig. *I*. which shows a closed glass tube d, into the ends of which are sealed wires that lead to a battery b. Inside the tube the wires terminate in electrodes a and c. The anode may be either iron or graphite, while the cathode c is mercury. The air is exhausted from the tube.

If by some means an electric arc is started from the anode to the cathode c, current will flow in the direction indicated by the arrows. To start the arc requires either that the difference of potential between the anode and the cathode be raised to an excessive value, perhaps 25,000 volts, or that the tube be shaken or tipped until the mercury forms a continuous stream between the two electrodes, and then reighted again to break the stream. As soon as the stream is made continuous, the current follos it, and then when the stream breaks, an arc is formed. The heat of the arc immediately vaporizes some of the mercury, and the vapor reduces the resistance of the path between the two electrodes sufficiently to allow the maintenance of an arc and, therefore, the flow of current form the anode a, to the cathode c. As long as the current flow is not interrupted a comparatively low voltage will maintain the arc.

The voltage required depends on the length of the arc and not on the strength of the current; that is, in a given tube the voltage across the arc will remain practically constant, even if the current strength varies. This may be explained by assuming that the greater the quantity of current, the more rapid is the formation of mercury vapor; hence the greater is the conductivity of the path between the electrodes. In all such devices, the formation of mercury vapor occurs at the cathode. With apparatus arranged as shown in Fig. and with sufficient condensing surface, and arc once established will continue as long as the necessary electric pressure in maintained between the electrodes, but if the arc is allowed to cease, even for an instant, it will not start again unless either an excessively high voltage is applied or the tube is shaken or tilted until the stream of mercury is monetarily continuous between the electrodes.

Another theory is that only the inoized vapor is a conductor of the current. This theory has not become fully established as yet , but the fact remains that too much vapor will smoother the arc.

If the vessel is not large enough to afford sufficient condensing surface the vapor soon becomes so dense that the arc goes out. If a single phase alternator of the commercial type and mercury rectifier placed in the circuit there would be no load thrown on the alternating current to direct current because the intervals in each current cycle short as they are, during which the current is zero, are sufficient in duration for the production of the conducting vapor to cease and the arc to go out. Experiment has shown that even with a 10,000 cycle alternating current, which gives 20,000 reversals per second-a frequence far beyond any commercial use- the reversals are not quick enough to maintain the arc.

The Cooper Hewitt mercury vapor converter is one of commercial use and will be explained with complete diagram of connections.

If the direct-current load is a storage battery, which is commonly called a live load, the converter is started by turning the switch lever l, Fig; 2 , to the right-hand contact j and closing both the alternating - current and the direct-current switch q,u.

Current then flows from the positive terminal of the storage battery w through the ammeter A-cut-out magnet k-sustaining coil l-tilting magnet n-cut-out switch p-starting resistance r-starting switch i-j to the negative terminal of the battery. On account of the resistance r, this current is too weak to operat the cut-out magnet k. The tilting magnet, however, tilts the bulb until the mercury connects the two electrodes s,s'; the current then flows through the mercury instead of through the tilting magnet, which is thereby so weakened that the bulb falls back to its upright position, thus breaking the stream of mercury between s,s" and therefore starting and arc from s to s'. The arc is at once picked up by one of the main anodes t,t', the current at first passing from the anodes to the cathode s', but the high resistance of the arc between s and s' causes the bulb to be tilted again almost immediately, and the arc is transferred to the main cathod s. The current is then forced back through the sustaining coil l, ccut-out magnet k, and the ammeter to the storage battery from which the returning current flows to the neutral point d of the transformer. The current through the cut-out magnet k is strong enough to open the circuit through r and s'. The main voltage regulation for the direct current is obtained by placing the plugs z,y in connection with suitable taps a,b,c,e, f,g,h, located along the autotransformer coil; the voltage with these plugs in any position may be futher varied somewhat by changing the position of an iron core in the regulating coil x, which varies the imedance of the coil. The plugs y,z are different in size so that z can only be placed in a,b, and c, and y in e,f,g, and h. When the apparatus is in operation, both the resistance r and the tilting coil n are cut out.

Fig; 3 is a diagram showing the principle parts of the converter laid out in a horizontal plane and also showing the connections. The anodes are connected to lugs 15 and 16, the starting electrode to lug 21, which is connected to lug 19, and the cathode to lug 22, which is connected to lug 20. The alternating-current wires are connected through suitable fuses to lugs 8 and 9, respectively; the path of the alternating current may be readily traced to the alternating-currnet switch on the switch-board. When this switch is closed, one side of the alternating-current circuit is connected through the switch to lug 10, and th other side through the switch and the regulator x to lug 11. Lug 10 and11 are connected, respectively, to lug 3 and 4; and from the latter extend flexible leads terminating in plugs y,z that may be inserted into various holes in a plugboard attached to the autotransformer, according to the voltage transformation desired. Lug 15 and 16 are connected respectively, to lugs 12 and 14, which , in turn, are connected to lug 5 and 7. From lugs 5,6, and 7, wires o',m, and o extend to the transformer, o;o, being connected to the extreme ends of the transformer coil and m to the middle, or neutral, point. Lug 13 is connected to lug 6 and also to the direct-current switch on the switchboard.

The two lower terminals of the direct-current switch are connected to the load- which may be a storage battery, a motor, or lights, and also to the voltmeter, so that if the load is s storage battery , its voltage may be read before closing the switch. One terminal of the ammeter is connected to the direct-current switch and the other through the cut-out magnet and the sustaining coil 1 to lug 20 on the connection board. The middle point of the starting switch, to which the switch lever is pivoted, is connected through the resistance spools, the cut-out switch, lug 19, and the tilting magnet to lug 20.

The left-hand contact point of the starting switch is connected to a terminal of the alternating-current switch, and the right-hand contact point to the negative terminal of the direct-current switch.

The plugs y, z on the ends of the alternating-current leads differ in sizes corresponding to the plugs, so that it is not possible to insert the plugs into holes in which they are not intended to go. The autotransformer should be set with the plugboard vertical, so as not to catch dust in the holes.

The eight holes in the plugboard, Fig. 3, are lettered a, b, c, d, e, f, g, h, corresponding to the similarly lettered taps in Fig. 2. Table 1 gives the plug positions necessary to secure various voltage transformations. Under each alternating-current voltage-200, 220, or 240-the two direct-current voltages given in the first column are the extremes that may be obtained, with the plugs in the given positions, by means of the hand regulating wheel shown at x. The table will serve as a guide in choosing the plug conbinations for different voltages.

The order in which the changes are made to raise or lower the direct-current voltage with any alternating-current voltage is the same; for example, the highest direct-current voltage with any alternating-current voltage is obtained with the plugs in holes b,i, and the lowest with the plugs in holes a,h. If it is desired to raise or lower the secondary voltage by changing the plugs, the necessary change can be made by following the sequence given in Table 1. A plug position should be chosen so that the exact voltage desired is obtained with the regulator plunger as far as out as possible, thus allowing the best circulation of

Table 1

Plug positions for voltage transformation

Alternating Current Volts 200		Alternating Current Volts 220		Alternating Current Volts 240	
80-130	b,f	95-140	b,f / c,g	105-140	c,g
75-120	c,g	90-130	b,g	100-130	b,g
70-110	b,g	85-120	c,h	90-120	b,h
65-100	b,h	85-95	b,h	85-110	a,f
60-90	a,f	80-110	a,e	75-105	a,g
55-85	a,f	75-85	a,f	70-90	a,h
50-70	a,h	70-100	a,g		
		65-95	a,h		
		60-80			
66					

air in the interior of the regulator. The plugs should be changed while the current is on.

When starting the converter on a live load, it will not continue to run unless the direct-current voltage of the converter is great enough to force more than about 5 amperes through the storage battery. If the converter starts and then goes out in a few seconds, the regulator handle should be turned to the right, to raise the voltage until the arc continues. The converter will run on a lower current when hot than when cold, and in order to run on a low current it is best to start on a higher one and then by turning the regulator handle to the left, when the apparatus is warm, reduce to the desired current. If when charging a storage battery the starting switch is left in the central position, the converter will automatically cut out without injury when the battery voltage rise enough to reduce the charging current to about 5 amperes.

If the converter is to be started on a load consisting of incandescent lamps or other resistance, which is termed a dead load, the alternating-current and the direct-current switches are closed, and the starting switch is moved to the left-hand contact, shown at j', Fig. 2 . An alternating current then flows through the resistance-the cut-out switch-the tilting magnet-the sustaining coil-the cut-out magnet-ammeter-and the load, to the autotransformer. This current tilts the bulb, allowing a current to flow across the electrodes s',s, and when the bulb rights itself the arc starts. The converter may also be started by hand, by tilting the bulb through a slot in the top of the cage. When running on a dead load, the starting switch may be allowed to remain on the left-hand contact, and, if the converter stops, due to the failure of the alteranting current from any cause, it will automatically start again when the current returns.

The rectifier considered consisted essentially of two graphite electrodes, a condenser, a small high potential transformer, two high potantial spark terminals, one consisting of a nickel alloy disc and the other a platinum iridium loop filament.

The platinum iridium loop forming one terminal of the high potantial circuit carries a low potential current which maintains the filament at a dull red heat. Under this condition the filament tends to throw off negative ions, and this tends to dissipate any negative charge it may have and produce a positive charge on the filament. In addition to the above mentioned condition, this same platinum iridium filament constitutes one terminal of the high potential alternating current transformer and as such is alternately charged positively and negatively while the corresponding opposite terminal (the nickel alloy disc electrode) is located at a dictance of 3/8 inch from the end of the hot platium loop. Under operating conditons the distance between the above mentioned terminals is adjusted so that the e.m.f. of the high tention transformer alone will not quite establish an arc across the air-gap, but with the assistace of the stream of negative ions thrown off from the hot platinum iridium dilament an arc will be established across this gap when the direction of the negative current consides with that of the stream of negative ions, although an arc will not be established by the same e.m.f. in the opposite direction.

The uni-drectional high tension arc thus established charges a small leyden jar condenser which disruptively discharges through the air gap between the artificial graphits electrodes, setting up in this air gap a high frequency oscillatory arc.. After this oscillatory arc has broken down the high resistance of the air gap, electifity flows from the main line to the load through the gap and the current thus established continues during the remainder of the particular half period in which it was started. When the main current ceases the arc is extingushed.

During the next half period the pilot spark will not start the arc because the stream of negative ions does not assist in breaking down the air gap when the e,m.f. is in this direction(i.e. positive current from hot platinum to cold nickel electrode) and hence there is no disruptive discharge from the condenser to start the main current across the carbon arc terminals.

Briefly summarizing the theory we may state that the rectifier consists of a graphite arc valve which has, in effect, in infinite resistance for current in one direction but for current in the other direction it has negligible resistance with a counter e,m.f. which consumes twenty-four volts irrespective of the amount of the current.

In order to determine conclusively whether electricity would flow through the rectifier in one direction only or both directions photgraphic records of the rectifier current waves were determined by means of the Ryan Cathode Ray Oscillograph. This device is peculiarly suited to such determinations since its moving parts have absolutely no mass or inertia. A careful examination of the oscillograph records obtained proves absolutely that no "Reversed Current" passes through this recitfier when it is adjusted for normal operation.

The efficiency of the rectifier varies with the conditions of operation, ther being five determining factors namely:

(a) the power required to operate the potential transformer,

(b) the counter e.m.f. of the main valve (the graphic arc),

(c) the e.m.f. of the supply circuit,

(d) the power delivered to the load,

(e) the power factor of the load circuit.

As the rectified current is uni-directional the power factor of the load will be unity for all cases in which the counter e.m.f. is always positive, as in hand operated arc lamps, storage cells, electrolytic and resistance loads of all kinds. In all such cases the efficiency of the rectifier will be represented by the follwwing equation:

$$\text{Efficiency} = 1 - \frac{24}{E} - \frac{38}{(E-24)I}$$

In which

E = applied e.m.f.

I = Current supplied to load

24 = e.m.f. consumed in the air gap

38 = watts consumed in the high transformer circuit.

The percentage of e.m.f drop at the main valve arc is $\frac{24}{E}$ hence $1 - \frac{24}{E}$ is the expression for the efficiency of the rectifier neglection the power lost in the transformer circuit, and this is the upper limit toward which the actual efficiency approaches as the load current is increased indefinitely. The values of this limiting efficiency for different e.m.f. are shown by the curve marked "A" on the a companying data sheet..

Curves marked "B" shows the actual efficiency of the rectifier for all values of current up to twenty-five amperes when oerating on a 120 volt ciruuit.

Curve marked "C" shows the actual efficiency of the rectifier for all values of current up to twenty-five amperes when operating on a 240 volt circuit.

Curves marked "B" shows the actual effieiency of the rectifier for all values of current up to twenty-five amperes when operating on a 120 volt circuit.

From these curves it may be seen that the practical operation of the rectifier on 120 volts circuits when delivering a current of 1/2 amperes or above will be at an efficiency of between 75% and 80%. Also it will be seen that when operating on 240 volt circuit when delivering 4 amperes or more the efficiency will be between 85% and 90%.

While with rectifier of larger size operating on circuits of higher e.m.f. and delivering greater current the efficiency of rectifiers of this type may rise somewhat above 95% as indicated by the curves, it should be mentioned that the particular rectifier under test was limited to approximately 27 amperes and 500 volts the maximum effieiency being 92%.

When reactive loads are being supplied with current the efficiency will naturally drop with a decrease in the power factor of the load.

As a result of actual trial it is certain that the rectifier is particularly well adapted for changing storage batteries from alternating current mains. The double valve type should prove suitable for continuous current arc lamps including those used for stereopticon and moving picture apparatus; the operation of X-ray apparatus designed to use continous current and the Wehnelt interrupter; and possibly it will be found suitable for moderate sizes of continuous current shunt motors.

For every small motors of the class it will certainly be applicable.

This is the results of the test made on the Murphy Electricity Rectifier at Cornell University, but the test made here was not satisfactory because good results was not obtained.

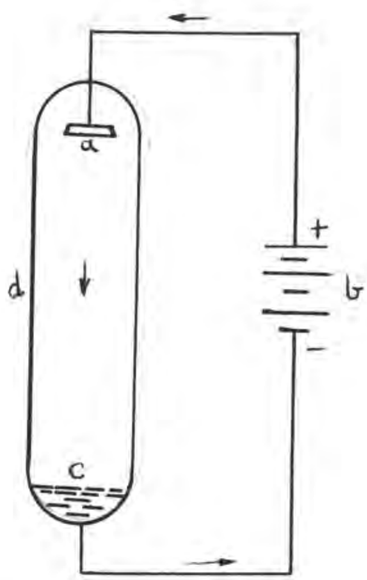
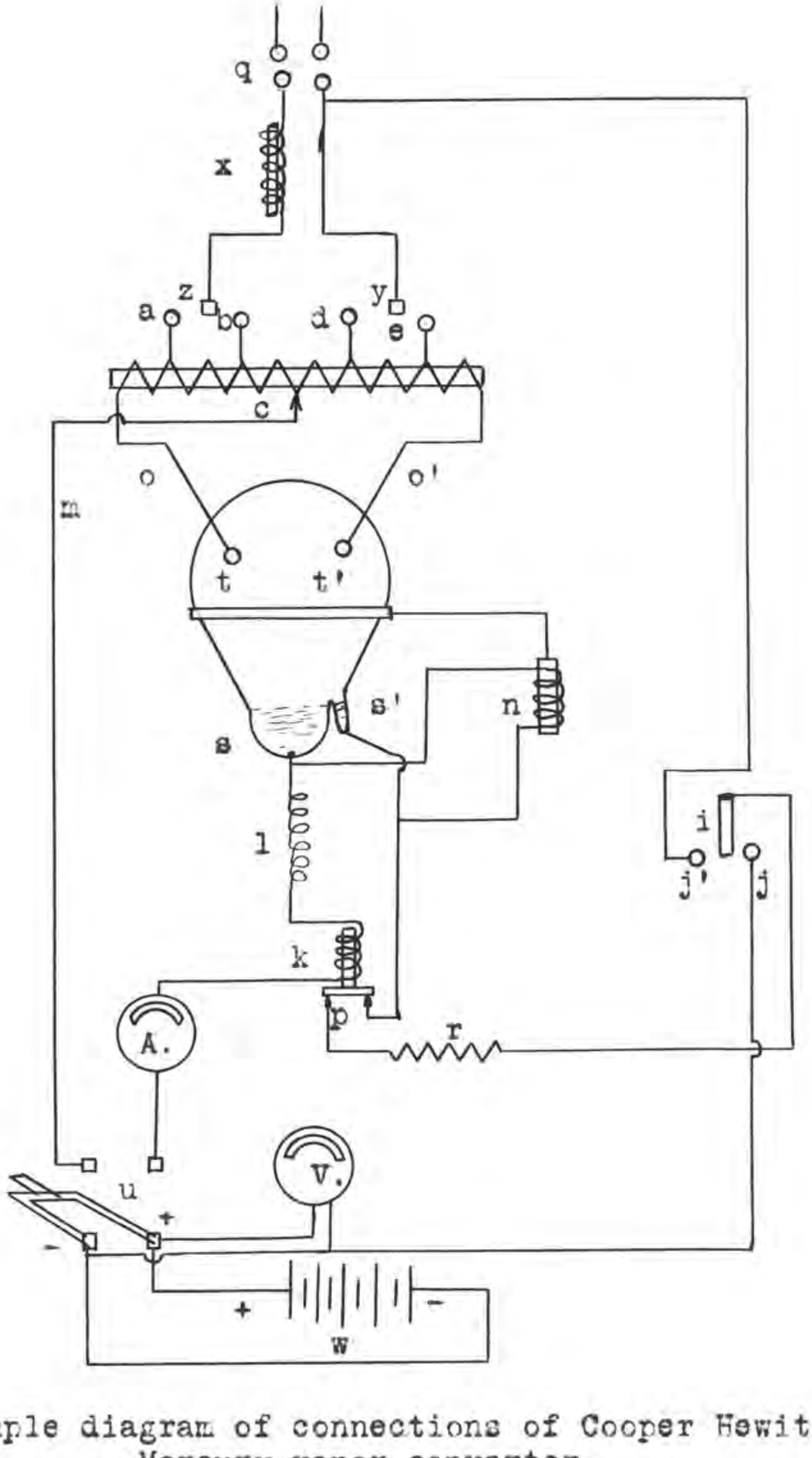
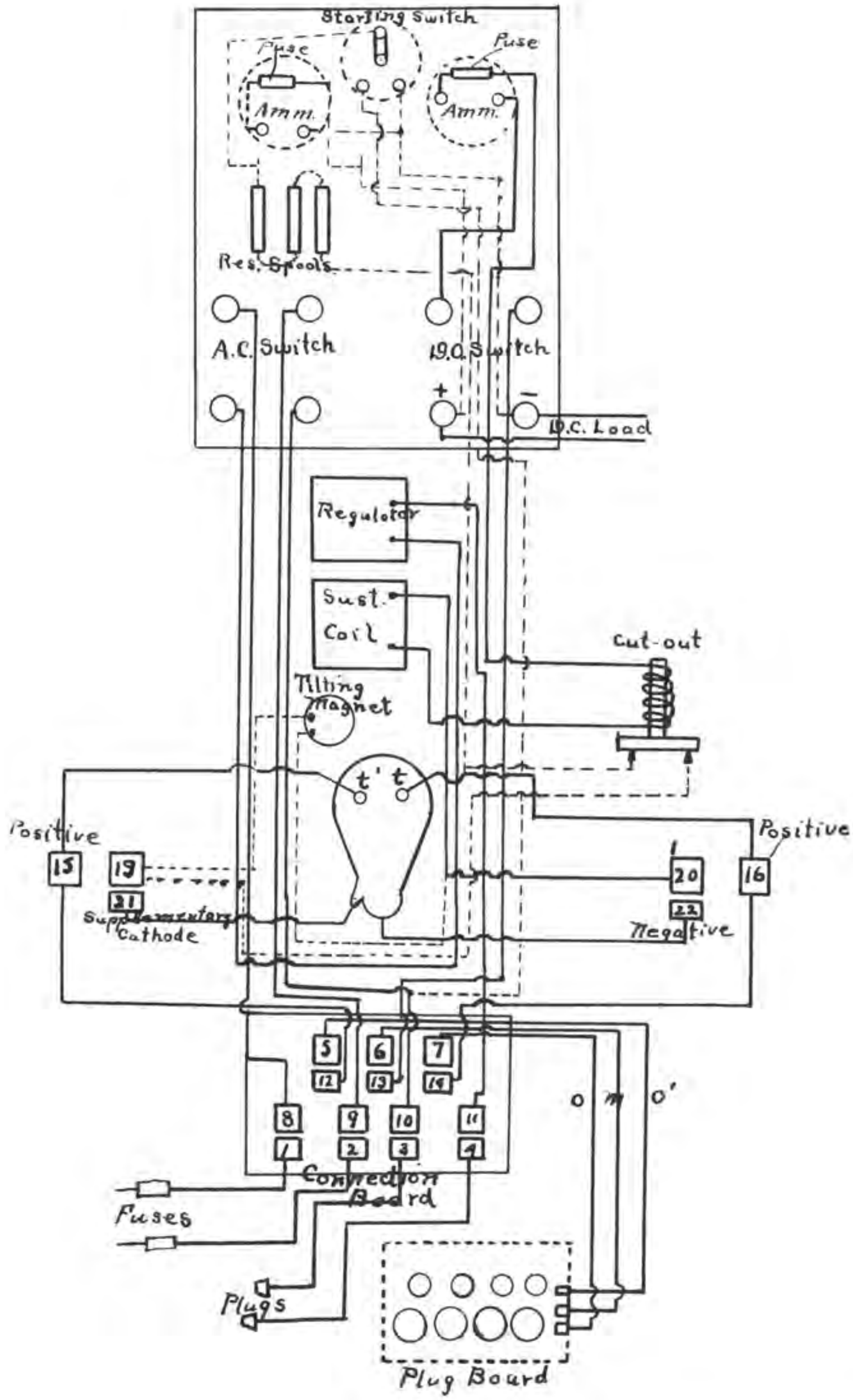


Fig. I



Simple diagram of connections of Cooper Hewitt
Mercury-vapor converter.

Fig. 2.



Complete Drawings of Switch Board for Mercury Arc.

Fig 3'.

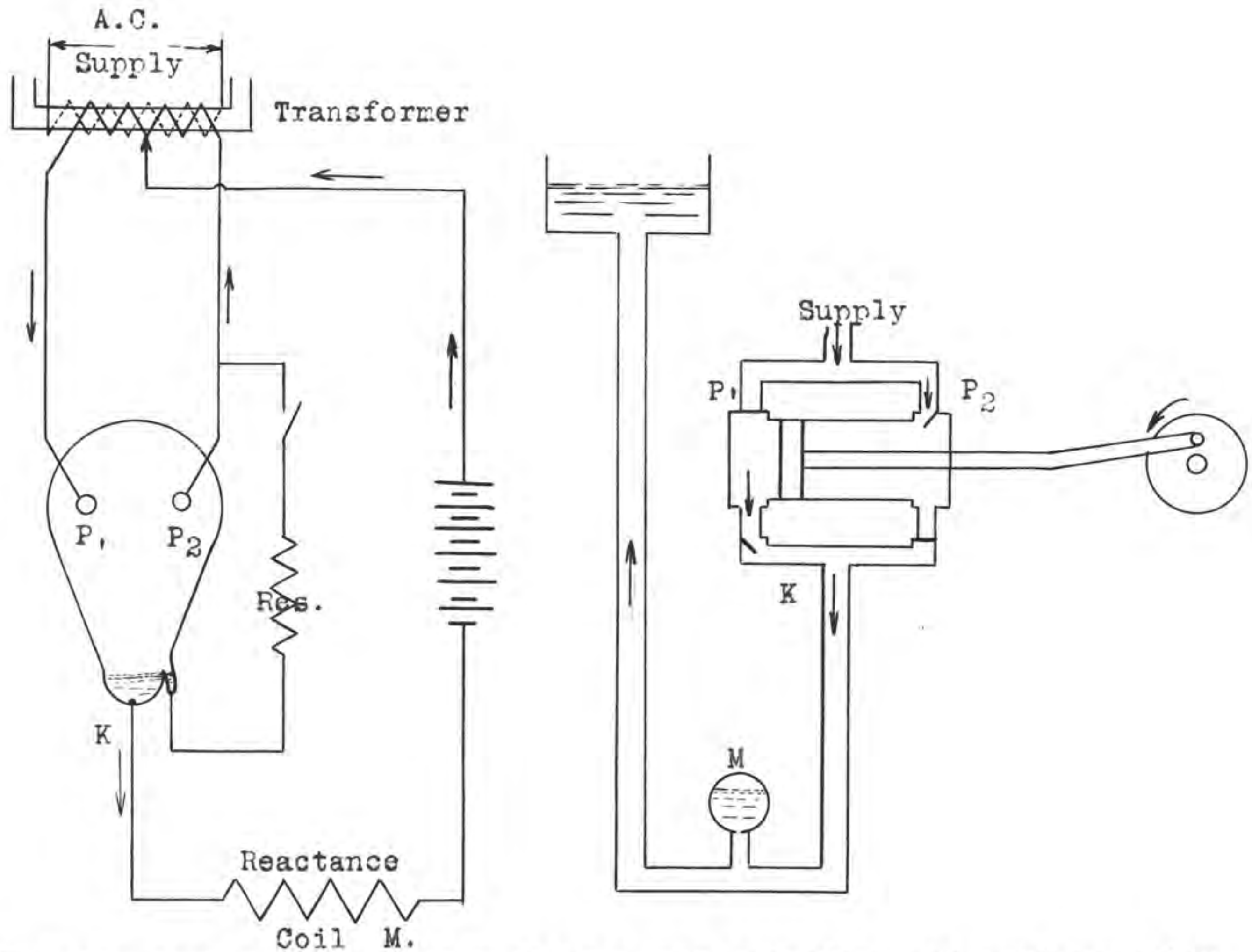
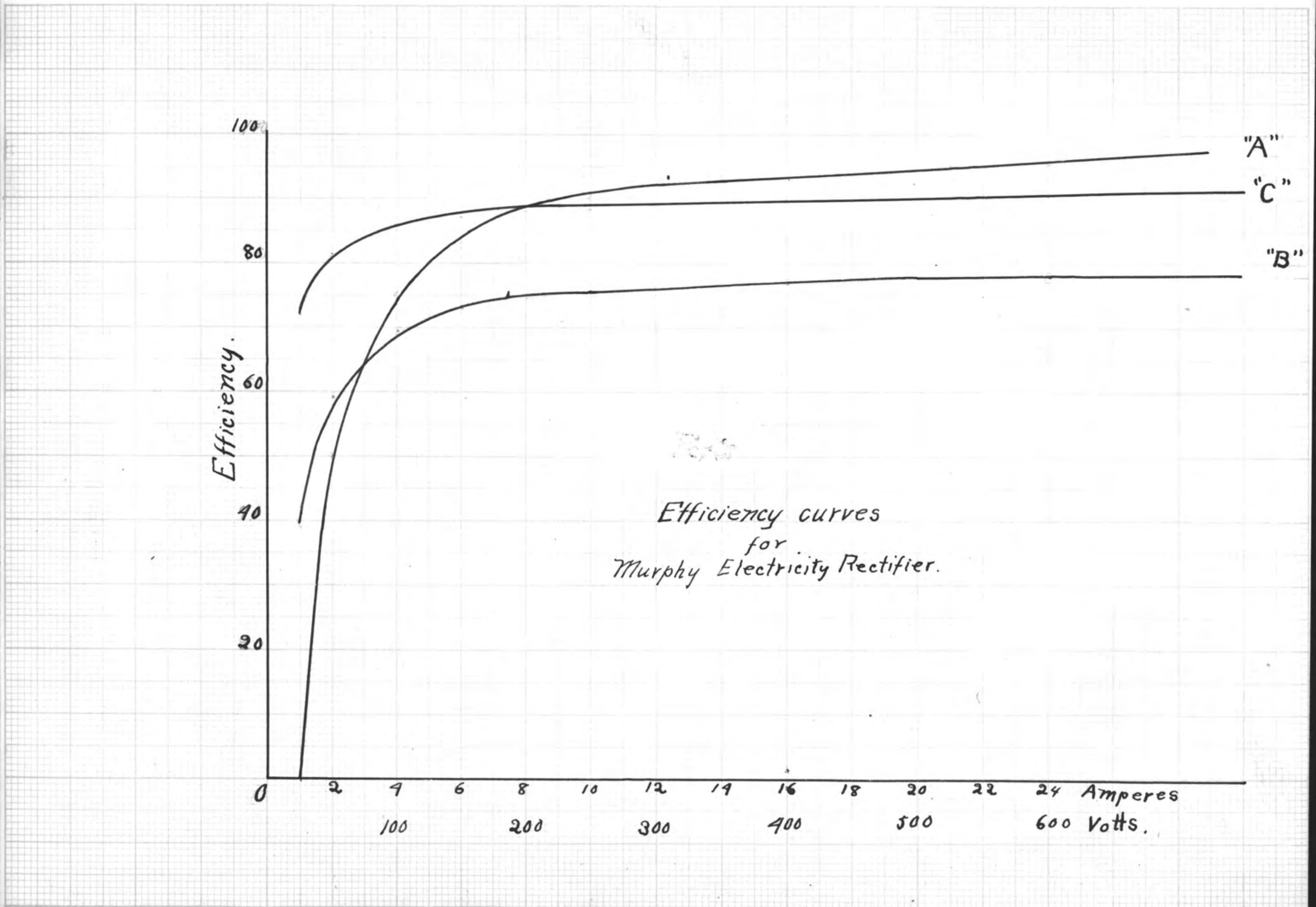


Diagram showing the analogy between the rectifier and reciprocating pump.

Fig. 4.


Efficiency curves
for
Murphy Electricity Rectifier.
Efficiency.
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
Amperes
100
200
300
400
500
600 Volts.
"A"
"C"
"B"