EFFICIENCY TEST, 3-PHASE, ENGINE TYPE, WESTINGHOUSE ALTERNATOR.

JUNCTION CITY, KAN.

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EFFICIENCY TEST OF WESTINGHOUSE ALTERNATOR # 276272.

Apparatus:--

Westinghouse Alternator # 276272.

Engine Type.

Three Phase,Y winding.

300 K.W.

100 R.P.M.

7200 Alt.

2300 Volts.

Instruments:--

Weston Wattmeter # 3897.

Weston Wattmeter # 1938.

Thomson Ammeter # 55194.

Thomson Ammeter # 47896.

Weston Voltmeter # 5614.

Crosby Steam Indicator #

Thomson Steam Indicator # 4123.

An alternator is a machine, having a field and an armature, which generates an alternating current.

The field may be either stationary or revolving, though usually of the revolving type. Nearly all the alternators of the present time are of the revolving field and stationary armature type, as it avoids the collection of high tension currents through brushes, since the armature may be permanently connected up, and only low tension direct-current need be fed through the rings to the field. Other advantages are, increased room for armature insulation, and, in polyphasers, the necessity for only two instead of three or more slip-rings. The revolving armature is still used to some extent on small machines of low voltage capacity.

The alternaing current is produced by passing a coil of wire first over a north pole and then over a south pole, so that a current is first generated in one direction and then in the other, in the inductors. The current changes direction in the coil every time that it passes under a pole of the opposite polarity. At a point between the two poles, in passing from one to the other, the coil passes for a very small increment of time over a space in which there are no lines of force being cut and at the same time there is no current or E.M.F. generatedin the coil. At this point the E.M.F. generated is of minimum value or zero; but as soon as the coil begins to enter the field of the next pole, the E.M.F.begins to increase in the opposite direction until the point under the center of the pole piece or field of greatest density is reached, when the E.M.F. reaches its maximum value and again begins to decrease to zero, after which it again rises and falls in the opposite direction.

When a current passes from zero to maximum and back again to zero, then to maximum in the opposite direction and again back to zero, it has passed through one cycle or two alternations. The number of cycles passed through in unit time, which is the second, is usually denoted as the frequency of the E.M.F. or current being generated. The frequency of the machine is equal to the pairs of poles times the number of revolutions divided by sixty or

$$f = \frac{p\ V}{60}.$$

where

f = frequency.

p = pairs of poles.

V = R.P.M.

60 = the number of seconds per minute.

The frequency of early alternators was as high as 125 cycles per second, while the alternators of the present time range from 25 to 60 cycles. The latter, after several years of service, have been seen to give the best results. In order to obtain these frequencies all commercial alternators must be made multi-polar, owing to the destructive speeds which would be required of a bi-polar machine. The peripheral speed of the rotating parts cannot much exceed a mile a minute so that in order to get a high frequency with reduced speed the multi-polar machines are used.

If when the coil in the armature is passing over the poles, the E.M.F. generated at each instant is plotted as the ordinates and time as abscissas, a curve will be obtained which almost approaches the shape of the sine wave. The curve will also show the time taken for compleeting a single cycle.

The curve obtained from the commercial machine is modified or distorted from a sine wave by the irregular distribution of the magnetic flux. Also uneven angular velocity of the generator will distort it by making it lower in the slow spots and higher in the fast ones, relative to the true sine curve. Differences in the magnetic reluctances in different angular positions, particularly if the inductors are laid in a few large slots. This will cause a slight periodic variation in the reluctance of the whole magnetic circuit and a corresponding pulsation of the total magnetic flux. All these influences operate at open circuit as well as under load.

The heat produced in a conductor carrying a current is proportional to the square of the current. In an alternating current, whose instantaneous values vary, the instanteneous rate of heating is not proportional to the instanteneous value, nor yet to the square of the average of the current values, but to the square of the instanteneous current values. And the average heating effect is proportional to the mean of the squares of the instanteneous currents.

The ratio of the effective E.M.F. to the average E.M.F. is called the form factor, since its value depends upon the shape of the pressure wave. As the curve becomes more peaked, its form factor increases, due to the superior weight of the squares of the larger ordinates. In the sinusoid the values found above give a form factor equal to

$$\frac{\dfrac{E_{max}}{\sqrt{2}}}{\dfrac{2\,E_{max}}{\pi}} = 1.11$$

Probably no alternators give true sine waves, but they approach it so nearly that the value of 1.11 can be used in calculation without sensible error.

The values of E.M.F. and current may be plotted together with the same abscissas. If the maximum of the current curve occurs at the same instant as that of the E.M.F. curve and also the two zero points coincide, the current will be in phase with the E.M.F. The power developed at any time by the machine is equal to the current times the voltage, which when in phase is always positive and the alternator is giving power to the line. When the current reaches its maximum or zero value at a time later than the corresponding value of pressure, the current is said to be lagging and out of phase with the pressure. This phase relation is usually represented by ø, which is measured in degrees along the X axis. In this case the product of the instantaneous currents times the instantaneous pressures will sometimes be negative or the line will at certain times give back power to the alternator. The same thing will again occur if the current is leading the pressure so that they are again out of phase. When the maximum current is reached at the same time as zero pressure we have a phase difference of 90° and the curves are said to be at right angles. When there is a phase difference of 90° the product of current times volts is half the time positive and half the time negative so that all the power given to the line by the alternator is given back again by theline to the alternator so that there is no work done.

The power for doing work is the difference between the instantaneous positive products and the instantaneous negative products of current times volts, as long as the phase displacement is not 90° or more, in which case the negative products would be equal to or greater than the positive . If the negative products were the larger the machine would be absorbing power from the line and acting as a motor. This would be possible only in the case of two alternators running in parallel. The power output of the alternator varies with the phase displacement ϕ and not with the current(I)and voltage(E), since, if the two are in phase the power is equal to (EI)but if 90° out of phase the power given out by the machine is zero; and varies between zero and EI for all intermediate displacements. Therefore the power is seen to be of E, I, and ϕ, and the relation is deduced as follows,

" Let the (') denote instantaneous values. If the current lags by the angle ϕ, then from a former equation,

$$E' = E_{max} \sin\alpha$$

where, for convenience,

$$\alpha = 2\pi ft,$$

and $$I' = I_{max} \sin(\alpha - \phi)$$

remembering that

$$E = E_{max}/\sqrt{2}\ , \text{ and } I = I_{max}/\sqrt{2} \quad \text{or}$$

$$E_{max} = \sqrt{2}\,E\ , \text{ and } I_{max} = \sqrt{2}\,I$$ the instantaneous power,

$$P' = E'I' = E_{max}\, I_{max} \sin\alpha \sin(\alpha - \phi)$$

Substituting values of E_{max} and I_{max} we have ,

$$P' = 2\,EI \sin\alpha \sin(\alpha - \phi)$$

But $\sin(\alpha - \phi) = \sin\alpha\cos\phi - \cos\alpha\sin\phi$,

so

$$P' = 2EI(\sin^2\alpha\cos\phi - \sin\alpha\cos\alpha\sin\phi)$$

Remembering that ϕ is constant, the average power over 180° will be

$$P = \frac{2EI\cos\phi}{\pi}\int_0^\pi \sin^2\alpha\, d\alpha - \frac{2EI\sin\phi}{\pi}\int_0^\pi \sin\alpha\cos\alpha\, d\alpha$$

$$= \frac{2EI\cos\phi}{\pi}\left(\frac{\alpha}{2} - \frac{\sin 2}{4}\right)_0^\pi - \frac{2EI\sin\phi}{\pi}\left(\frac{\sin^2\alpha}{2}\right)_0^\pi$$

or

$$P = EI\cos\phi .$$

Should the current lead the pressure by ϕ°, then the leading equation would be,

$P' = 2EI \sin\alpha \sin(\alpha+\phi)$, which gives the same expression,

$P = EI\cos\phi$, which is the general expression for the power in an alternating current circuit." The true power may be found at any time then by multiplying the volts by the amperes and also by the cosine of the angle of lead or lag.

Self-Induction accompaines all alternating current phenomenon though it is sometimes very small or else it has been overcome by the capacitance of the circuit. Inductance is a back E.M.F. set up by the current in the circuit which opposes the changing of the current which produced it. In starting a current in a conductor the lines of force set up by the current are cut by the conductor as they pass along; this sets up an E.M.F. which opposes the on-coming current the same as a resistance. Then when the current begins to decrease again the lines of force are cut again by the conductor which tends to maintain the current at its former value and to keep it flowing in the same direction. The inductance of a circuit varies directly as the square of the number of turns in the conductor; as the linear dimensions if the coil changes its size without changing its shape; and inveresly as the reluctance of the magnetic-circuit, if all the conditions remain constant, save those under consideration.

The reactance of the circuit due to inductanee is equal to $2\pi fL$, where f = frequency, and L is in henries. The reactance is at right angles to the resistance so that the impedance or apparent resistance of a circuit is equal to $\sqrt{R^2 + \overline{2\pi fL}^2}$.

Alternators have high self-induction which makes it possible to run them on short-circuit without burning out the armature. It also makes the conditions more favorable for the parallel running of alternators by decreasing the liability of their getting out of step so as to cause one machine to get more than its proper proportion of the load.

Capacity in an alternator has the same effect upon the machine as induction but 180° from it so that one may be overcome by the increase of the other. The capacity reactance of a circuit is equal to

$$C = \frac{1}{2\pi f C}$$

where f = frequency

C = farads.

The Impedance of a circuit containing R, L, & C, is

$$\text{Imp.} = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}.$$

Capacity acts the same as a resistance in theline but at 90° from the resistance. Capacitance is obtained by putting a condenser in the circuit, usually for the purpose of overcoming inductance.

Alternators may be single or polyphase, containing from one to any number of phases. Since polyphase currents are equally well adapted for lighting and power, the polyphase machine is the one in general use.

Polyphase currents are generally more economical for transmission purposes. The polyphase alternator is less expensive than a single phaser owing to the increased size of the single phaser for the same output.

Windings for any number of phases may be wound on a single armature core, and these may be separately connected to an outside circuit through sliprings, or they may be so connected together in the armature according to some scheme where-by one slip-ring will be common to two phases. These windings can be so placed and connected as to give any desired voltage or phase relation with each other. The three phase system is the one most commonly used.

The pressure and current relations in a three phase alternator are usually difficult to determine. Consider three similar coils, X,Y,Z, on a ring armature, each covering 120°, as in Fig.1(a). The E.M.F!s generated in thesecoils, when they are rotated in a bi-polar field, they will have the same maximum values, but will differ in phase from each other by 120°. If two of the coils, X and Z be connected as in (b), then the pressure between the free terminals will be the resultant of the two E.M.F's at 120° with each other.

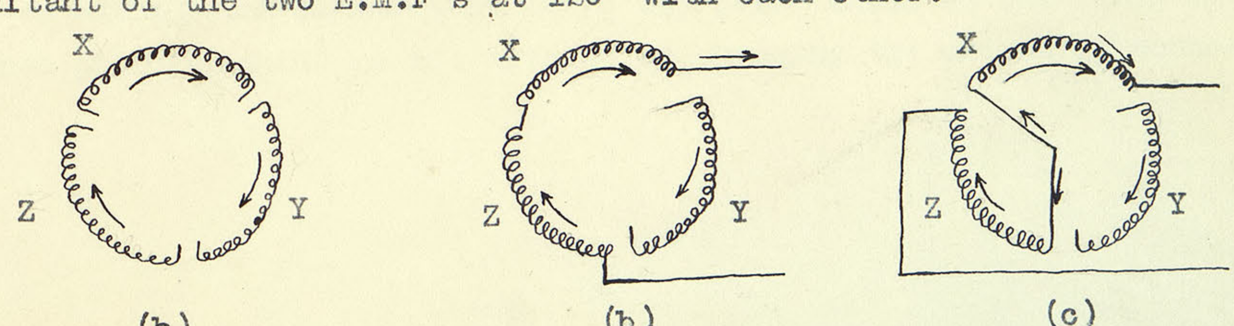


Fig. 1.

If, instead of this connection, the one shown in (c) be used, known as the "star" or "Y" connection, the pressure between the free terminals will be the result of subtracting the E.M.F. of coil Z from that of X at 120°. Subtraction is necessary because the connection of coil Z to the circuit has been reversed. To subtract one quantity from another it is but necessary to change its sign and add. Therefore the pressure between the free terminals is that which results from adding the E.M.F's of X and Z at 300°, or 120° 180° as shown in Fig. 2. It is $\sqrt{3}$ E volts. The star connection is generally represented as in Fig. 3., where the pressure between any two line wires is $\sqrt{3}$ E volts, and the current in each line wire is I amperes.

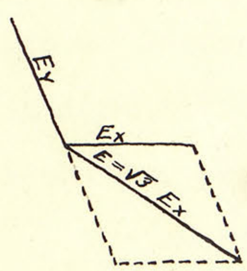


Fig. 2.

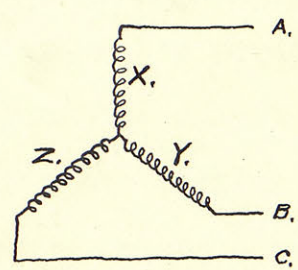


Fig. 3.

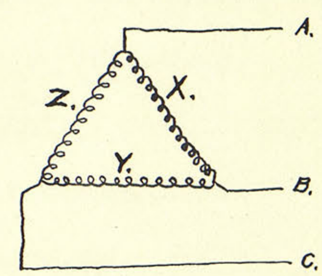


Fig. 4.

If the coils be connected as in Fig. 4, the result is termed a "DELTA" or mesh connection. The pressure between any two of the line wires is E volts. Each line wire is supplied with current from two coils, connection being made at the junction between the beginning of one coil and the ending of the other. The value of the current in each wire is $\sqrt{3}$ I amperes. This results from subtracting the current in one wire from that of the other at 120°, which, as before, is the same as adding the currents at 300°. The power which is delivered by a three phase machine is not altered by changing the method of connection.

In one case each phase is supplied with I amperes at $\sqrt{3}$ E volts, and in the other case with $\sqrt{3}$ I amperes at E volts. At any instant the current in one phase of a three phase system is equal and opposite to the algebraic sum of the currents in the other two phases. For this reason three wires easily carry the current of a three phase system, the third wire acting as a common return for the other two lines.

The Y connection is made where the highest voltage possible is to be obtained. It is used for transmission purposes as the higher the voltage the lower the current; which willproduce the smaller line loss, for the same sized conductors. In this form of connection the voltage is increased 1.7 times its normal value for the other connections without altering the output of the machine or increasing the liability of trouble in the working parts of the machine.

The average pressure generatedin an armature is,

$$E_{av} = 2 \cdot p \cdot \phi \cdot S \cdot V \,/\, 60 \cdot 10^8$$

where

p = pairs of poles.

ϕ = maxwells of flux per pole.

V = R.P.M.

S = number of inductors.

In an alternating current, $E = K' \cdot E_{av}$

where

K' = form factor, the ratio of the effective to the average E.M.F. Hence in an alternator yielding a sine wave E.M.F.,

$$E = \frac{2.22 \cdot p \cdot \phi \cdot S \cdot V}{60 \cdot 10^8}$$

Inasmuch as $\frac{p\ V}{60}$ represents frequency (f),

$$E = 2.22\ \phi\ S\ f\ 10^{-8}.$$

An alternator winding may be either concentrated or distributed. If, considering but a single phase, there is but one slot per pole, and all the inductors that are intended to be under one pole are laid in one slot, the winding is said to be concentrated, and if the inductors are all in series the E.M.F. will be that given by the above formula. Now if, the inductors are all laid in separate slots closely adjoining each other, the E.M.F. generated in the inductors of any one slot will be 1 divided by thenumber of slots of thatgenerated in one slot in the first case, and the pressure in the different slots will differ slightly in phase from each other, since the inductors in each slot generates its maximum at a slightly different time from the rest. The phase difference between the E.M.F. generated in two conductors which are placed in two successive armature slots, depends upon the ratio of the periphereal distance between the centers of the slots to the periphereal distance between two successive north poles considered as 360°. This phase difference angle

$$\phi = \frac{\text{Width of slot} \cdot \text{width of tooth}}{\dfrac{\text{Circumference of armature}}{\text{\# pairs of poles}}}\ (360).$$

If the inductors of several slots were to be connected in series, the total E.M.F. would be the vector sum of the voltages for each of the slots as

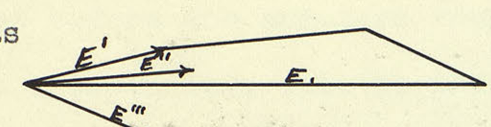


FIG. 5

E' = the sum of the voltages in all the inductors of slot (1) connected in series.

E" = sum of the voltages of all the inductors in slot (2), and
E'"= the voltage of the inductors, etc.

E = sum of the voltages in all the slots in series.

The armature reaction of an alternator consists of two parts, distortion and magnetization or demagnetization. These depend upon the number of ampere turns in the armature and upon whether it is a leading or a lagging current. The maximum pressure is generated in a coil when its opposite inductors are respectively under the centers of north and south poles.

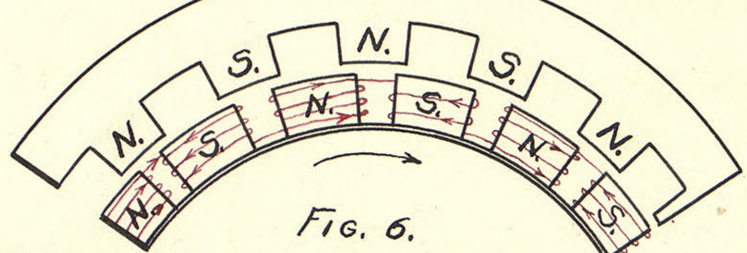


FIG. 6.

This condition is repreasented in Fig. 6. If the armature current is in phase with the E.M.F., poles will be set up in the armature as shown in Fig. 6. The flux set up in the armature at this time distorts that set up by the field poles so that the magnetic path is lengthened and the magnetic reluctance is increased. Now if the current is lagging the maximum current will be produced when the armature has passed the position shown in Fig. 6, so that a north pole will be produced more nearly under a north field pole and a south pole under a south field pole, so that the two fields oppose each other, causing a demagnetizing effect as well as a distortion. If the current be leading the opposite will be true and the maximum current will be generated before the armature reaches the position shown in Fig. 6, so that a south pole will be produced more nearly under a field north pole and a north pole under a field south pole, causing the armature current to help magnetize the field poles.

The more the cuerent leads up to 90°, the greater the magnetizing effect upon the field poles, while the reverse is true of a lagging current.

The synchronous impedance of an alternator is made up of the armature resistance and the synchronous reactance. This impedance times the current is equal to the voltage drop in the machine. This can be found by short-circuiting the alternator and running it at normal speed with just enough field excitation to produce the required load to be read by an ammeter, then open the circuit and read the voltage which will be the drop for the load just measured and the impedance is

$$Imp = \frac{E}{I}$$

where

E = open circuit voltage.

I = short-circuit current.

---:REGULATION:---

One of the greatest problems connected with alternators, is that of regulation. By regulation, as discussed here, is meant, the maintainance of a steady voltage under changing conditions of load.

There are, in general, two sets of conditions which may result in poor voltage regulation. The first and most serious of these is due to the operation of induction motors on a lighting circuit. The second is due to the rise and fall of potential with changing load.

The latter can be overcome by hand regulation, but good regulation in the former condition can be best secured by automatic devices.

The most common way of exciting the alternator field is from some separate source. Alternators are also designed where-by the current to excite the field is taken direct from the alternator armature, but thisis not as satisfactory as separate excitation. The General Electric Co. have an alternator designed in which the field current is taken from a D.C.armature which is built on the same shaft with the field of the alternator.

There are two general methods of separate excitation in common use. One is to have a D.C.machine separately driven, which generates current for the fields of several alternators. The other method is to have a D.C.generator belted to the alternator shaft. This is the method used on the alternator upon which this test was made.

Where the exciter is connected directly to the alternator shaft, the alternator field input will be affected by the speed of the alternator. Hence, if this speed is not constant, or nearly so, the voltage of the alternator will vary.

In an Engine Type Alternator, as the machine tested, the variation of the speed is very small, being in this case only one R.P.M. from no load to full load, which makes practically no variation in the alternator field input.

In a three phase system the voltage over each circuit would be the same, providing the conditions on the line were the same, and the resistance and inductance of the three armature windings were also the same. The latter are generally about the same, but the former are almost without exception, different over each line. In the case of the alternator tested, the total load consisted of incandescent lamps, arc lamps and three phase induction motors.

An incandescent lamp load is practically non-inductive, and is fairly constant, so that regulation is easily maintained. Arc lamps are inductive and give more or less difficulty in regulation. The most difficult conditions, however, occur when induction motors are placed on the same line with the incandescent load. The bad effects of the induction motor are:- first, large induction which creates a back E.M.F. which is 180° out of phase with the impressed voltage. This cuts down the voltage and causes a lagging current. Second, the motor loads vary from almost no load conditions up to 25% over-load, which causes blinking of the lights if there is no adequate means of regulation.

For lighting loads very fine regulation is desirable, and consequently, automatic regulators are indispensible. Several types of regulators are in use today, but the one most commonly used is the Tirril Regulator.

TIRRIL REGULATOR.

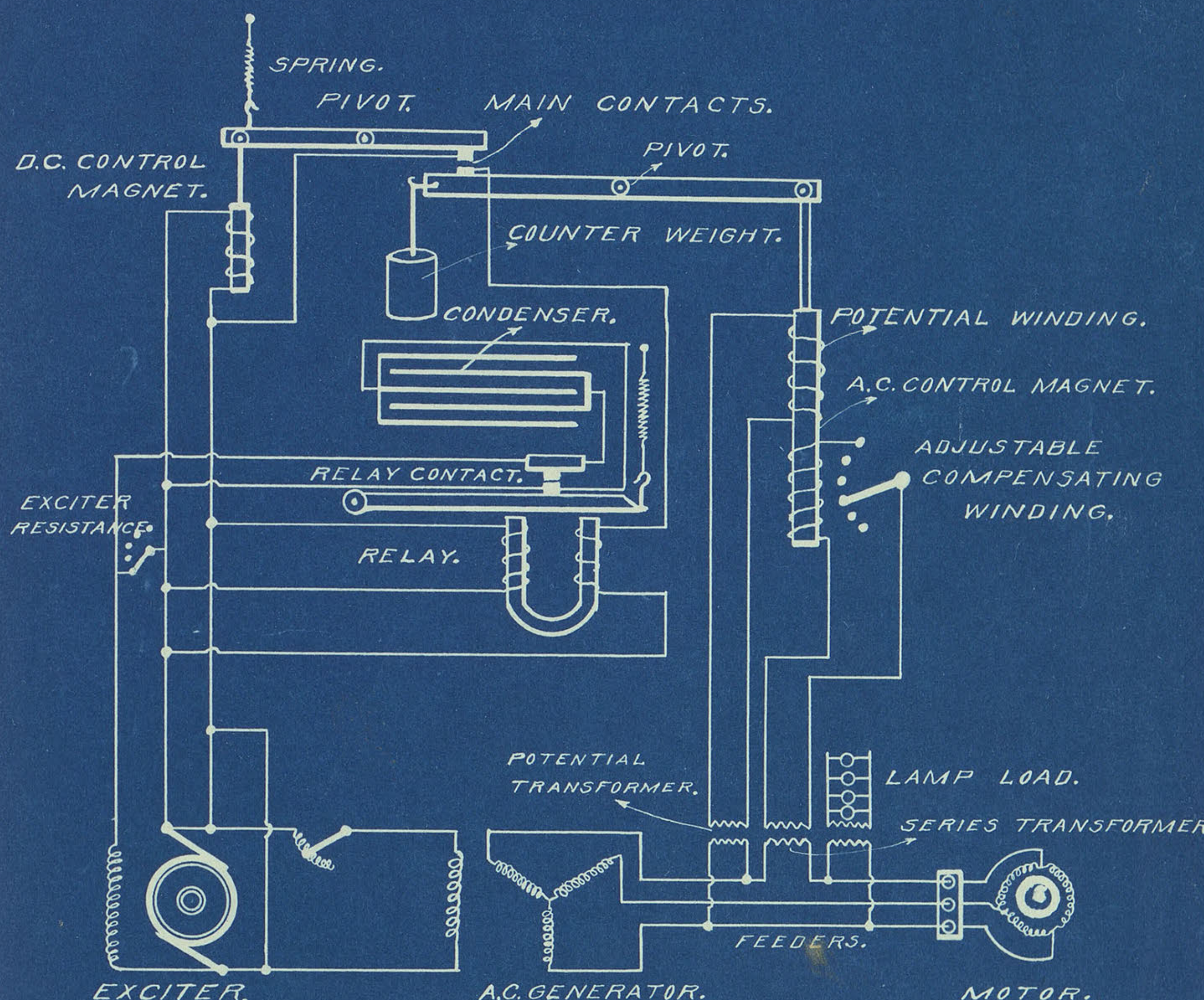


DIAGRAM SHOWING CONNECTIONS OF THE TIRRIL REGULATOR, FOR CLOSE VOLTAGE REGULATION, WHERE LOAD MAY BE VARIABLE, INDUCTIVE & NON-INDUCTIVE.

G.C.K.

This regulator is in use in the Junction City plant, and almost every other up-to-date plant. The following is a discussion of the Tirril Regulator and its operation.

A series transformer is placed in the line. This current transformer is connected to a coil placed about a magnet core in the regulator. A potential transformer is placed across the circuit over which the regulator is to operate, and this transformer is connected to another coil which is differentially wound, with respect to the coil connected to the series transformer. The current from the series transformer is dependent upon the current on the line only. The current from the potential transformer on the other hand, varies with the change of line voltage. Now when both of these currents are equal the magnet core will be neutral as their magnetizing effects are always opposing. When the magnetizing effect due to the series transformer is the greater the bar will be pulled down. This occurs when the line voltage drops. If the line voltage is raised to normal, the magnet is released, and the counter-weight at the opposite end of the magnet lever, brings the magnet back to its original position.

The principle upon which regulation is affected is the cutting in and out of resistance in the shunt field of the exciter. In parallel with the shunt field resistance is a condenser. A shunt line runs from the exciter mains to a D.C.control magnet which when magnetized acts against a spring which tends to hold in a constant position the bar to which the magnet is attached. When the current through this D.C.core is great enough the spring will be overcome and the magnet will be pulled down, thus tending to separate the points of main contact between this bar and the bar of the A.C.magnet.

In parallel with this D.C.magnet circuit is a line which is wound about one leg of a relay magnet, and terminates in the two points of main contact between the two control magnet bars. Now when the line voltage falls the A.C.magnet is pulled down, causing contact to be made between the two bars of the control magnets. This permits a current to pass through the coil of the relay magnet causing it to repell a bar at the ends of its poles which short-circuits the shunt field of the exciter. This raises the exciter voltage and hence increases the current to the alternator field, which in turn raises the volatge at the terminals of the alternator. The instant the line pressure is raised to normal, the A.C.control magnet coils release their pull on the core and the contact is broken, thus throwing in the resistance in the shunt field of the exciter again. This same operation occurs very rapidily, especially if the regulator is well set, and maintains a very steady voltage at the alternator terminals.

The current required for operating the A.C.magnet is about 2 amperes at 100 to 125 volts.

The condenser is for the purpose of avoiding excessive sparking at the relay contact.

The counter-weight is so adjusted that it will just balance the magnet bar when the proper voltage is maintained on the line.

The line voltage with the regulator out is, in general, about 65% of what it is with the regulator in.

As the induction motor load varies, and hence the potential over the line tends to vary, the Tirril Regulator compensates for the drop and the voltage is held practically constant. A well adjusted regulator will only allow a variation of a few volts on the line. About 2% regulation is considered good for lighting purposes.

The construction of an alternator has a great deal to do with its regulation. Large armature reaction and large inductance are disastrous to good regulation. For good service, alternators of low inductance and armature reaction should be used. Where the load is non-inductive, compound alternators are generally used, the compounding, compensating for the drop in voltage due to the load, but where inductive loads are to be supplied, regulators must be used. Compounding will furnish fairly good regulation on inductive loads of constant power-factor, but where the power-factor is a variable it is entirely unsatisfactory.

Polyphase alternators afford much better regulation than single phasers, as the increased number of windings necessary to produce the polyphase currents, diminish the inductance and armature demagnetization. In accordance with this, we find that the reaction in a three phase machine such as that tested, can be reduced by distributing the windings. Instead of using one winding per phase, the winding is split up into several sets of coils in adjacent slots.

In the case of regulators, either hand or automatic, the resistance or regulating devices are put in the field of the exciter as there is less current through the exciter field, and hence there will be less I^2R loss than if the resistance were placed in the alternator field, that is, the exciter mains. Hand regulation is seldom used except on non-inductive loads, or inductive loads with constant power-factor.

--: TRANSMISSION:--

The power obtained from the alternator is distributed over Junction City, and a part is transmitted to Ft.Riley, and there distributed for lighting purposes.

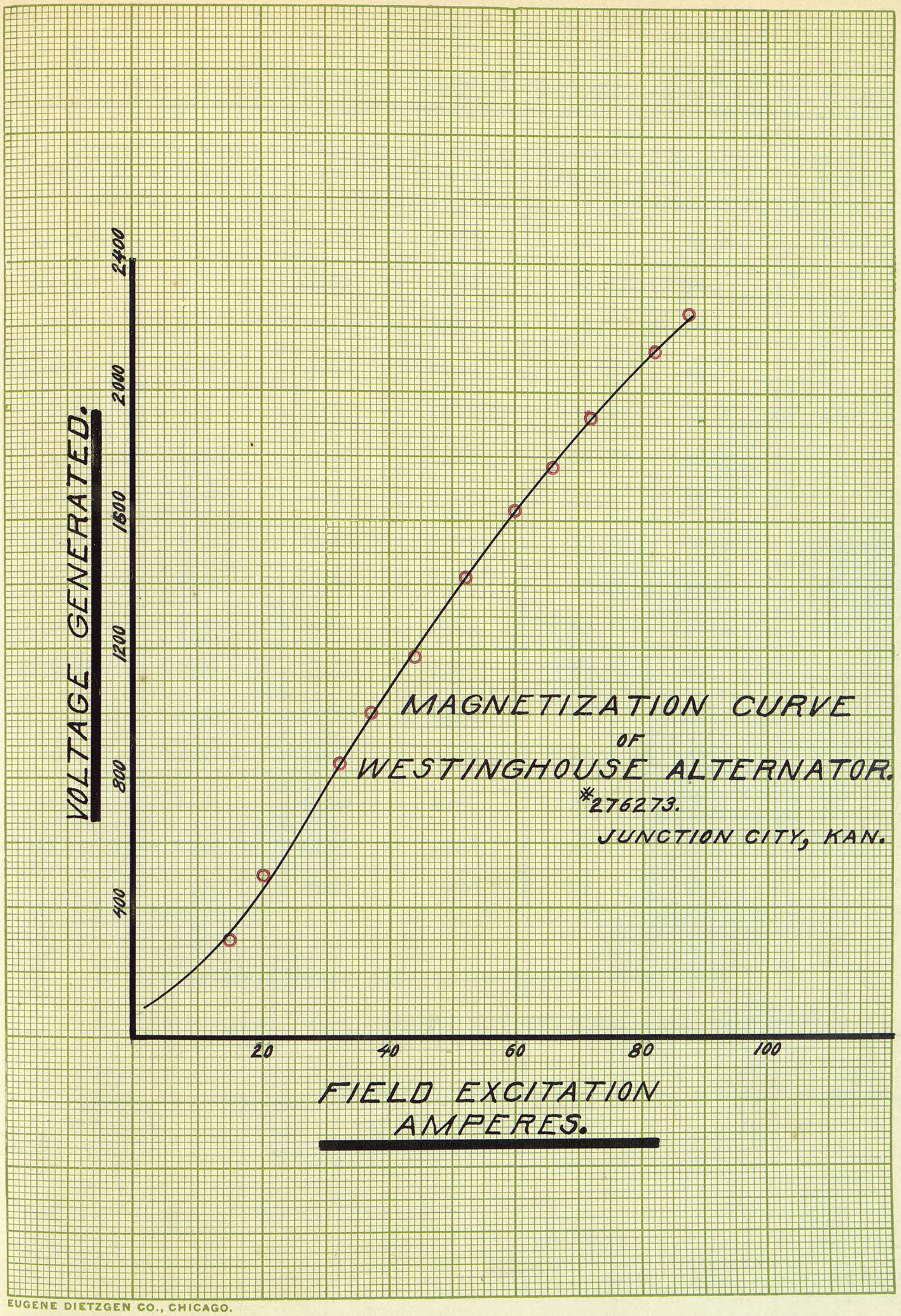
The Junction City consumption is for arc lamps, incandescent lighting and for induction motor work. The largest consumption of the power is for the lighting, both arc and incandescent, as the test was made at a time when the motors were not running.

The arc lights are designed for constant current work, and receive their supply through a constant current transformer of the air cooled type.

The power for the arc lights at Ft.Riley is generated at 2300 volts, but is stepped up to nearly 2600 volts for transmission purpose. This stepping up of the voltage, only on the Ft.Riley circuit is to allow for the IR drop due to the transmission.

DATA ON MAGNETIZATION CURVE OF WESTINGHOUSE ALTERNATOR # 276273.

Generator Voltage	Field Excitation in Amperes,
300	15
500	20
850	32
1000	37
1190	44
1420	52
1630	60
1770	66
1920	72
2130	82
2260	87.5



EUGENE DIETZGEN CO., CHICAGO.

DATA ON THE EFFICIENCY TEST OF WESTINGHOUSE ALTERNATOR # 276273.

Output in K.W. Leg # 1.	Leg # 2.	Generator Voltage 1 - 2	2 - 3	Generator Amperes Leg # 1	Leg # 2	Speed R.P.M.
3.425	3.4	2130	2240	45.	37.8	101.
4.33	3.97	2100	2240	55.75	44.	
4.7	5.3	2215	2290	60.	49.	
4.7	5.32	2230	2290	60.	49.	
4.75	5.4	2230	2290	60.25	49.8	100.
4.8	5.42	2230	2290	60.75	50.	
4.86	5.43	2230	2290	61.	50.	
4.7	5.45	2240	2295	59.	50.2	100.
4.55	5.25	2250	2300	57.5	48.3	
4.43	5.2	2250	2300	56.	47.5	
@ 3.4	4.3	2280	2290	41.	39.	101.
2.9	4.2	2270	2260	39.	38.	
3.0	4.1	2270	2260	38.5	38.	
1.9	3.2	2290	2270	21.	28.	101.
*1.	3.6	2290	2265	25.	31.	101.
# .8	3.7	2300	2270	26.	33.	101.

@ Synchronous Motor running as load, over excited.

* Synchronous Motor running as load, under excited.

N.B. The readings of the Wattmeters are to be multiplied by 20.

DATA ON THE EFFICIENCY TEST OF WESTINGHOUSE ALTERNATOR # 276275.

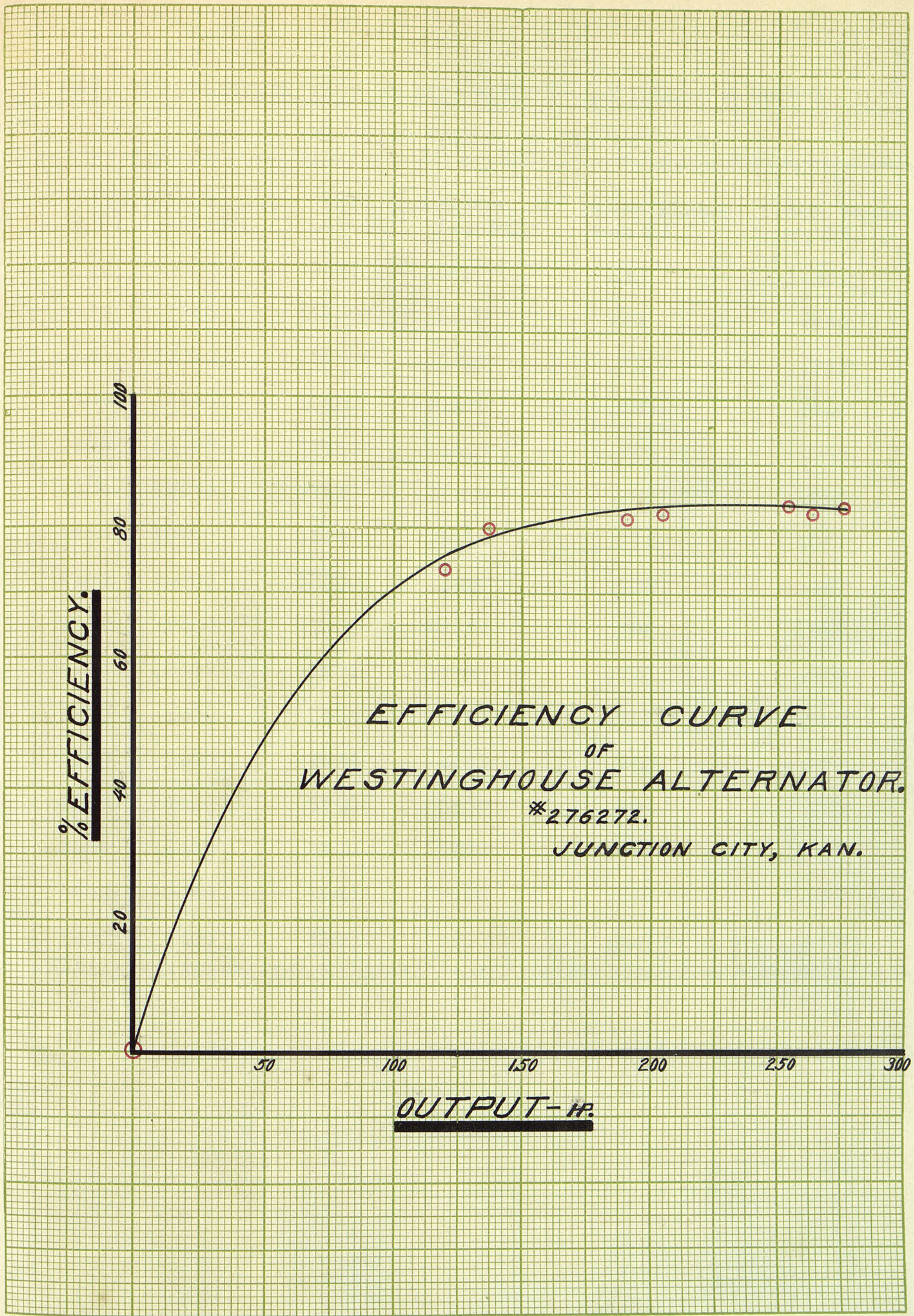
Input in HP. High pressure cylinder.	Input in HP. Low pressure cylinder.	Total Input H.P.	Total Output H.P.	Efficiency %
150.	79.1	229.1	183.	80.%
156.8	114.1	270.9	222.5	82.2
192.5	136.3	328.8	268.	82.
187.3	136.8	324.1	268.5	828
188.1	143.1	331.2	272.	82.2
188.	143.5	331.5	274.	82.6
186.2	145.5	331.7	276.	83.3
184.5	145.7	330.2	272.	82.3
184.5	133.8	318.3	263.	82.5
179.5	130.5	310.	258.5	83.4
145.	106.5	251.5	206.5	82.2
139.	95.	234.	290.5	81.5
146.5	92.9	239.4	190.5	79.6
106.	64.9	170.9	136.8	80.
103.5	60.9	164.4	123.2	75.
103.	61.	164.	120.8	73.6
* 26.9	13.92	40.82		0.0
¢ 17.25	5.1	22.35		0.0

* With the Alternator field excited to 87.5 Amperes.

¢ With no field excitation on the Alternator.

The reading of the input of ¢, is the power consumed by the machine in overcoming friction and windage.

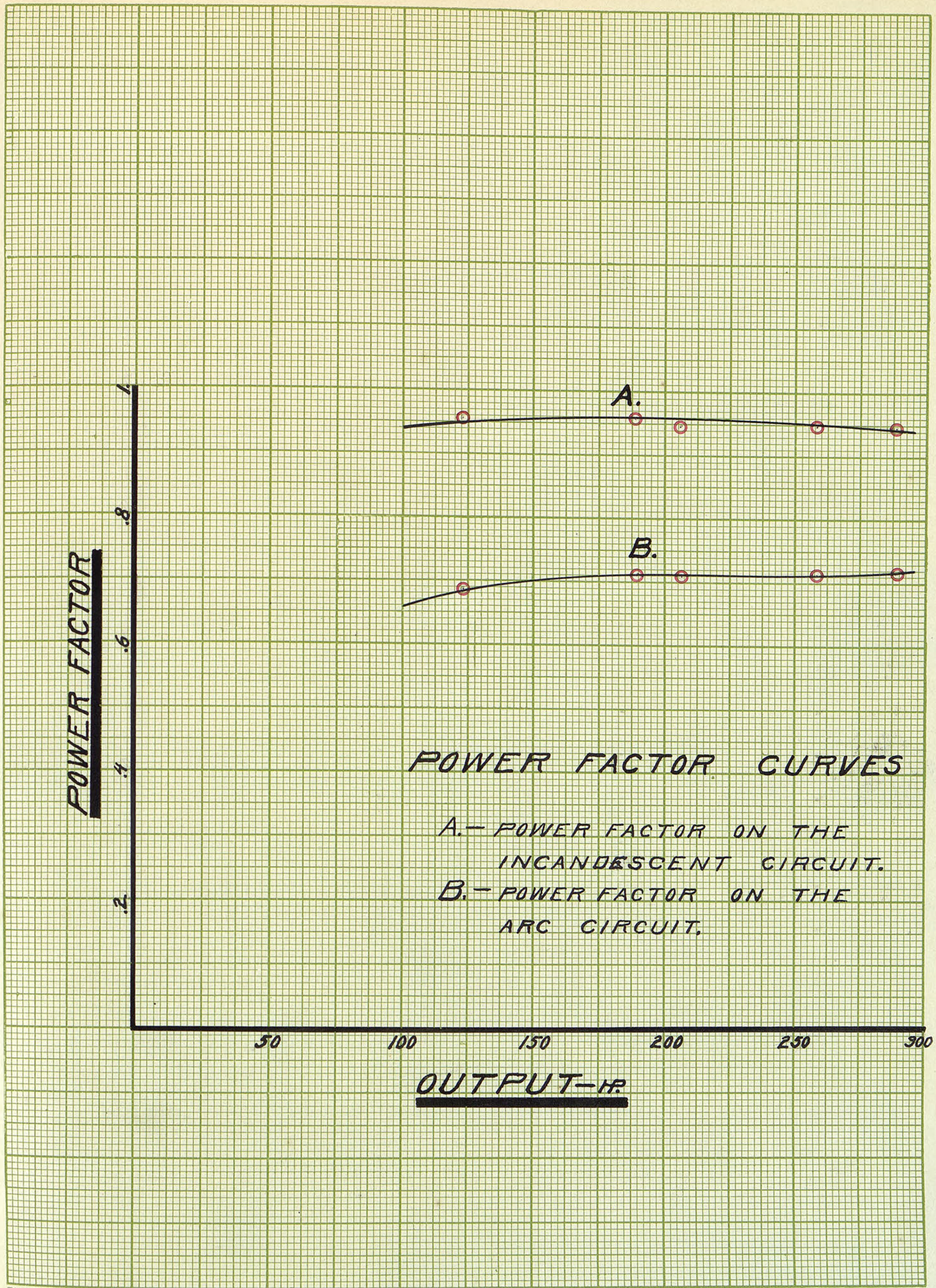
* If the reading of ¢ be subtracted from this one of *, the remainder will be the power consumed in the core of the Alternator.



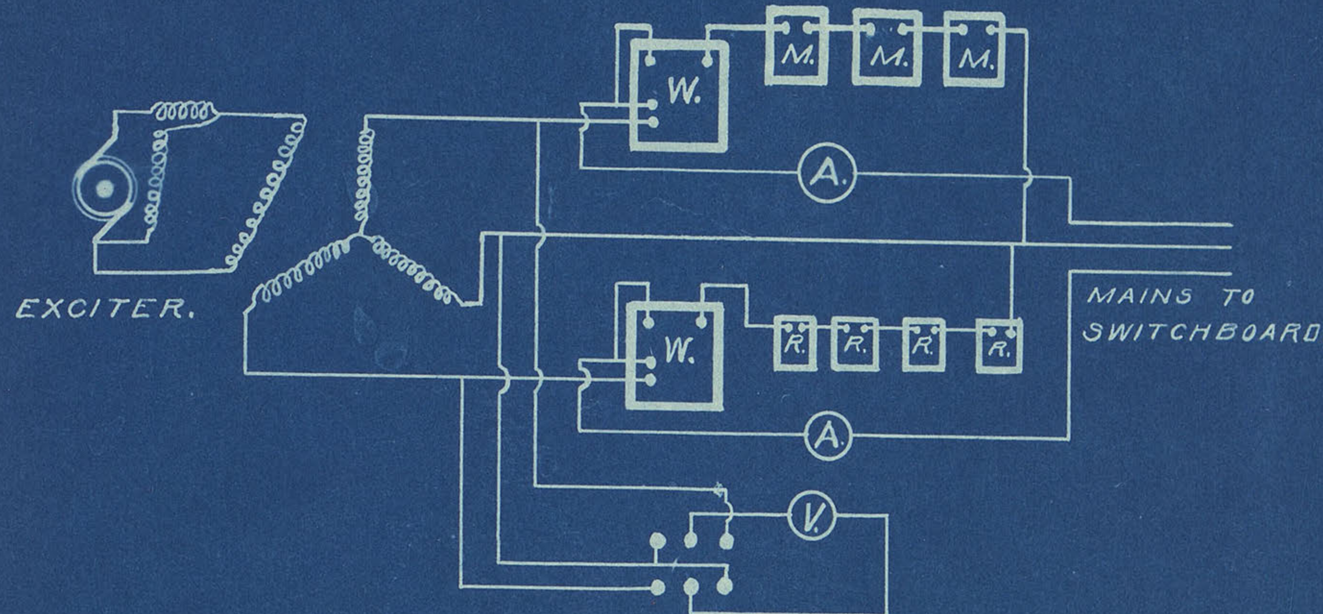
EUGENE DIETZGEN CO., CHICAGO.

DATA ON THE POWER FACTOR OF THE CIRCUITS.

Output in Watts. Leg #1	Output in Watts. Leg #2	Volt x Amperes Leg #1	Volt x Amperes Leg #2.	Power Factor Leg #1	Power Factor Leg #2.
7850	6800	9580	6460	.82	1.05
8660	7940	11700	9850	.74	.806
9400	10600	13220	11220	.71	.945
9400	10640	13380	11220	.703	.949
9500	10800	13420	11420	.707	.945
9600	10840	13530	11460	.708	.946
9720	10860	13590	11460	.715	.947
9400	10900	13200	11520	.712	.947
9100	10500	12950	11120	.702	.944
8960	10400	12600	10920	.711	.952
6800	8600	9350	8920	.727	.962
5800	8400	8870	8600	.655	.977
6000	8200	8750	8600	.685	.953
3800	6400	4810	6360	.79	1.005
2000	7200	5740	7020	.349	1.023
1600	7400	5980	7500	.267	.987



EUGENE DIETZGEN CO., CHICAGO.



SCHEME, SHOWING CONNECTIONS AND POSITION OF INSTRUMENTS FOR EFFICIENCY TEST OF

WESTINGHOUSE ALTERNATOR

276273.

JUNCTION CITY, KAN.

G.C.K.

---THE ALTERNATOR TEST:---

The generator tested was an engine type, direct connected three phaser with a Monarch Corliss compound condensing engine as a prime mover. The engine was a 500 HP with both low and high pressure cylinders. The diameter of the high pressure cylinder was 17" and that of the low pressure cylinder 34", so that the ratio of the areas of the two wase as 1:4, making thepower delivered by one cylinder almost equal to that of the other. The stroke of the piston was 3' and the R.P.M. was 100, making a point on the piston travel 600' per minute.

The alternator was of the revolving field type, and a 300 KW capacity generator having 72 poles or 36 pairs of poles in its revolving field. The frequency of the machine is

$$f = \frac{36 \times 100}{60} \quad \text{or 60 cycles.}$$

The frequency is such as to be equally well suited for both lighting and power loads. The fieldsaare separately excited by a D.C.dynamo, belt driven from the alternator. The exciter is large enough to carry more than twice the exciting current of the alternator before reaching its maximum load. The armature of the alternator was wound 3 phase with a Y connection, so as, to produce the highest voltage and cut down the line losses.

The three lines were run from the generator to the instruments on the switchhboard and then to an oil switch which connected them to the distributing lines carrying current to all parts of the city. The connections on the switchboard were such that it could be operated in parallel with the other A.C. machines of the plant, in case of high loadsand when switching from one machine to the other in case the load should be too great for a smaller unit.

The first test made was to determine the magnetization curve by reading the voltage across the open terminals of the machine, and varying the field excitation from zero to normal value. Readings of the magnetizing current and armature volts on open circuit were taken and recorded for each variation.

A curve was then plotted with armature volts as ordinates and field current as abscissas. The curve obtained is composed of two parts, the first part being slightly convex to the X axis for a short distance showing that the fieldpoles contain a small amount of residual magnetism. This part of the curve has been exagerated a little in plotting so that the ability of the pole pieces to hold residual magnetism might be better shown. In alternators the field cores are made of very soft iron and the residual magnetism is reduced almost to zero. The fields of alternators are always separately excited so that there is no advantage in designing the field cores so as to hold a small amount of residual magnetism; as in D.C.machines which are self exciting and must retain a small amount in order to be able to generate enough current for excitation.

The second part of the curve is almost a straight line being slightly concave to the X axis. This part of the curve shows the voltage to increase almost directly as the field excitation. For this part of the curve the permeability of the iron is almost constant or $B/H = \mu$, a constant.

where

B = number of lines of force per sq.cm.in iron.

H = number of lines in air, for the same magnetizing current.

This part of the curve is usually known as the straight part of the curve and usually approaches very nearly the shape of a straight line.

By increasing the field excitation still farther the curve would have extended on in the same direction until the field cores became saturated, when it would have drooped toward the X axis until it would have finally become almost parallel to the X axis. The alternator when heavily loaded in order to keep up its voltage must be worked upon the upper part of the bend of the curve so that small demagnetizing effects will not affect the voltage generated enough to be noted. The generator is at all times worked beyond the part plotted for normal voltage except on open circuit, where the normal voltage is produced when working upon theupper part of the curve plotted. The armature reaction when loaded cuts down the voltage to such an extent that the field excitation must be considerably increased before normal voltage is again generated. The impedance of the armature causes the greatest fall in voltage as the voltage drop is equal to IR_1, where I equals armature current and R_1 equals the impedance of the armature. All these drops in voltage must be overcome by increasing the field excitation and working the alternator higher up on the magnetization curve. For close regulation, as in lamp loads it is found to be best to work the alternator above the bend on the magnetization curve.

The second test made was that for the efficiency of theunit from the engine cylinder to the switchboard. In this the connections were made as shown in Fig.7. By placing a wattmeter and ammeter in each of two of the circuitsusing the third wire as a common return. By the use of a two way switch one voltmeter was made to read the voltage over the two circuits containing the instruments by first switching on one circuit and then the other.

b The unit was run from six oclock P.M. until 1 A.M., and readings of the different instruments taken simultaneously at different times, so that a reading for each different load was obtained. Simultaneously with the other readings the indicated HP for both ends of each cylinder was also taken with two different Indicators. The speed was taken at several different times and was found to be practically constant at 100 R.P.M.

From this data the indicated HP of the engine was determined. The indicated HP of the engine is the energy required to operate the generator. This is the input into the generator and is equal to the generator output plus all thelosses in both the generator and engine. The output of the generator was obtained by two wattmeters.

The losses in an alternator are; first, bearing friction and windage, second, molecular magnetic friction and eddy-currents in copper, iron, and other metallic parts; third, armature resistance loss, which may be expressed by pI^2R; where R is the resistance of one armature circuit or branch, I is the current in such circuit or branch, and (p) is the number armature circuits or branches, fourth, load losses; the load losses cannot well be determined individually, yet, they may be considerable, and their joint influence should be determined by observation. This can be done by operating the machine on short-circuit and at full load current, that is, by determining what may be called the (short-circuit core loss). With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exagerated.

One third of the short-circuit core loss, may, as an approximation, and in the absence of more accurate information be assumed as the load loss. Collector ring friction and contact resistance. These are generally negligible, except in machines of extremely low voltage.

Field excitation. In separately excited machines, the I^2R loss of the field coils proper should be used. In self exciting machines, however, the loss in the field rheostat should be included.

As it is difficult to determine these different losses it is usually customary to measure the total input and the total output and from this find the efficiency.

The efficiencies of the generator at the different loads were found and a curve plotted with per cent efficiency as ordinates and HP output as abscissas. This curve shows the efficiency of the generator to be 80% or better for the different loads. For the very smallest or loads below 125 HP the efficiency is less. The highest efficiency obtained for any of the loads was 83.4% which is a fairly good efficiency for a machine of that size and at less than full load. For full load the efficiency would probably be 2 or 3% higher though the increase of load did not change the efficiency but little for a large variation of load. The largest load obtained was about two thirds the capacity of the machine, showing the efficiency of the machine to be good over a large variation of load.

The efficiency of this unit might be increased by cutting down the size of the exciter so that the exciter might also be run at its highest efficiency. As it is the exciter runs at less than half load, causing its efficiency to be greatly reduced which also reduces the efficiency of the generator unit.

The efficiency of a direct connected unit is higher than that driven in any other way, as the belt or gearing losses are all reduced to zero, allowing the extra power to be given up to the generator. In large units this loss would amount to many HP.

The wattless current on the line caused by a low power factor also assists to cut down the efficiency of a unit, by heating the coils and increasing the resistance which in turn increases the I^2R loss in the armature. The extra loss due to this wattless current is the total current squared times the increased resistance due to theheating effect of the wattless current plus the wattless current squared times the resistance of the armature. This extra loss amounts to a great deal with a low power factor and at all times helps to reduce the efficiency of a generating unit. The lagging current has a demagnetizing effect on the fields which must be overcome by increased excitation, which is also an extra loss tending to decrease the efficiency. For this reason a dynamo with an incandescent lighting load is more efficient than one with an arc lamp or induction motor load, as the last two produce a lower power factor than the first.

The power factor upon the incandescent lighting load was found to be almost constant for all loads and considerably above .9 while that on the arc lamp load was also almost constant but much lower due to self-induction in the lamps and regulator.

The self-induction or inductive resistance on the line tends to throw the currentout of phase with the E.M.F. so that a wattless current is left on the line to surge back and forth through the alternator.

The core losses of the alternator were found to be almost as great as the windage and friction losses. This was partly due to the large current being generated by the exciter for the alternator. If the exciter load was taken away so as to have only core loss, it would be found to be much smaller.

NO-LOAD CARDS.

80# SPRING.

HIGH PRESSURE CYLINDER CARD.

H.E. = .235 □"   C.E. = .20 □"

M.E.P. = 4.56   M.E.P. = 3.88

I.H.P. = 17.25

16# SPRING.

LOW PRESSURE CYLINDER CARD.

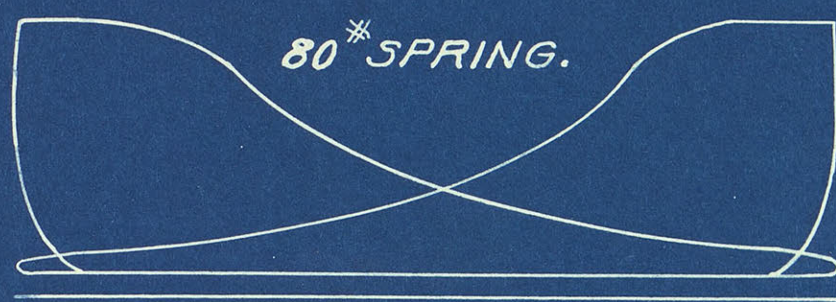
H.E. = 0.0 □"   C.E. = .15 □"

M.E.P. = 0.0   M.E.P. = .62

IHP = 5.1

G.C.K.

MAXIMUM LOAD CARDS.

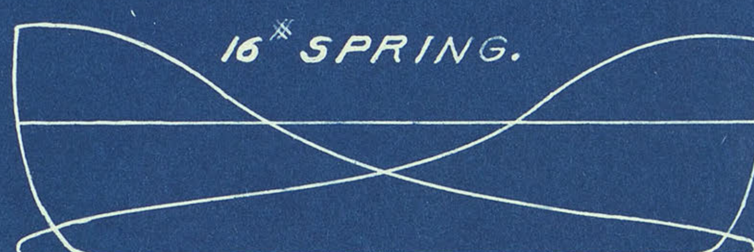


HIGH PRESSURE CYLINDER CARD.

H.E. = 2.5 □" C.E. = 2.43 □"

M.E.P. = 46.3 M.E.P. = 45.

I.H.P. = 186.2



LOW PRESSURE CYLINDER CARD.

H.E. = 2.07 □" C.E. = 2.18 □"

M.E.P. = 8.58 M.E.P. = 9.0

I.H.P. = 145.5

G.C.K.

The efficiency of a generating unit depends in some degree upon the efficiency of the prime mover. In this case it is of the greatest importance that the steam as well as the electrical part of the unit be properly regulated and operated. The indicator diagram shows the working of the piston and the opening and closing of the valves during a complete revolution of the engine.

The card for maximum load shows that the engine is working properly. The admission line is very nearly vertical, thus indicating that the admission valve is opened to admit the steam to the cylinder when the engine is very nearly on dead center. The steam line is a little short and the cut-off valve should be set so that it would not be closed so quickly. This would not be noticed if the engine were carrying a full load. Theexpansion curve approaches very closely to a parabola and indicates that there is a gradual decrease of the pressure in the cylinder as the steam expands. The exhaust line shows that the steam exhausts very closely to the atmospheric pressure yet there is enough back pressure in the cylinder to prevent knocking of the piston head.

The cards for the mean and even down to about one fourth load, resemble that for the maximum load with noticable changes that the steam line is decreased as the load is decreased and the different parts of the diagram become less distinct.

For loads less than one fourth load it is seen that the valves are not correctly set as the different parts of the diagram are not distinct and as is seen by the loop during part of the stroke, is absorbing instead of giving off power.

By an inspection of the cards taken for the entire run, it is found that the efficiency of the engine for the night's run might be increased by opening the steam valve so that the steam would be admitted for a longer period as the diagram shows that the cut-off valve is closed too soon and hence the area of the card is decreased which indicates a smaller I.H.P.