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Commercial Tests of a Transformer.

The financial success or failure of a lighting or power enterprise is measured by the efficiency of the machinery, and the efficiency of the machinery depends upon that of each piece of apparatus of which it is composed. In alternating current distribution the transformers are frequently scattered in large numbers throughout the system, and their accumulative losses, forming a large part of the total energy wasted in the system, greatly effect the efficiency of the plant.

Transformers are devices used for raising or lowering the voltage in alternating current circuits. The use of such saves much expense in transmission of power. Electrical power must be transmitted at a high voltage or the cost of copper will be excessive. High voltage however is very dangerous and also many kinds of apparatus demand low voltage, therefore transformers must be used to lower the voltage. Thus it is seen that the use of transformers greatly reduces the expense of the plant.

A transformer consists of two windings placed on the same iron core; one winding called the primary is connected to the power supply; the other called the secondary is connected to the load, the receiving circuit. The primary alternating current produces in the core an alternating magnetic flux, which in turn induces voltage and consequently currents in the secondary winding.

Transformers may first be classified as to the style of winding. If the electric surround the magnetic ciruits, that is if the core is inside the coils of winding the transformer is of the core type. If the core surrounds the coils the transformer is of the shell type. In the shell type the iron is cooler than the rest of the transformer, but in the core type it is hotter. As the "ageing" of the iron, or the increase of the hysteretic coefficient with time, is beleived to be caused by heating, this is claimed as a point of superiority of the shell type. However the primary object in keeping a transformer cool is to protect the insulation and not to save the iron. The core type has less iron and generally less iron loss, so the advantages are not very much in favor of either type. Both types are built or used by the same company in many cases.

Transformers may be classified as the ratio of transformation, which is the ratio of the number of turns in the secondary coil to the number of turns in the primary coils. If the ratio of transformation is greater than unity, the transformer is called a "step-up" transformer and it delivers electrical energy at a higher voltage than the voltage at which it was received. Step-up transformers are used chiefly in generating plants where the alternators do not generate current of sufficient high voltage for economical transmission.

If the ratio of transformation is less than unity the transformers is called a "step-down" transformer.step-down transformers find their greatest use at the points where the energy is distributed to the consumers. The use of the transformer is to raise or lo wer the voltage in alternating current is much cheaper than the use of the motor generator set in direct current.

Transformers are also named in regard to the method of keeping them from heating excessively. Some transformers have enough radiating surface to take care of all the energy lost through heat but the large transformers must have some artificial method to reduce t their temperature. There are three common methods of cooling transformers; by direct radiation and conduction to the air; by water circulation; and by air blasts. in the first two methods the transformer is immersed in a tank of oil. The outer surface of the surrounding t tank should be large enough to radiate the heat quickly. These are called self cooled transformers. A water cooled transformer is one which has coils of pipe in the oil of the above tank through which cold water is circulated thus keeping the oil cool and consquently the transformer.

In air-blast transformers the heat is dissipated by means of a blast of air forced through the coils by motor driven blowers.

If the coils of wire of a transformer had no resistance, if there was no magnetic leakage and if the reluctance of the iron core were zero there would be no losses in the transformer and it would deliver as much power as it received. But this is not the case as that could be possible in an ideal transformer. In the actual transformer however, the coils always have more or less resistance;some of the magnetic flux; some of the so-called leakage flux; and further, a certain amount magnetomotive force or ampere turns are necessary to force the magnetic flux through the transformer core. Thismakes the action of the transformer quite complicated. The behavior of the actual transformer is however in many respects quite similar to the behavior of the ideal transformer. We find that in actual practice of operating that itis only necessary to consider or make use of the theory of the ideal transformer which is very simple, but in designing, one has to take into consideration the effects of coil resistance, magnetic leakage, and core reluctance.

The iron losses in a transformer are practically the same in amount at all loads.They depend first upon the frequency,upon the flux density,upon the quality and quantity of iron,and also upon the thickness of the laminations.

The copper loss is nearly zero when the transformer is not loaded, but increases with the square of the current and becomes very excessive when the transformer is greatly over-greatly overloaded.

When we speak of the efficiency of a transformer it is understood to be the ratio of the power output divided by the power input. The efficiency is very low when the output is small; and it increases as the output increases, reaches a maximum and falls off again when the output is very great. The falling off of the efficiency of a transformer when the output is great, is said to be due to the great increase of copper loss.

The "all-day" efficiency of a transformer is the ratio of energy output to the energy input during twentyfour hours. We find that the usual conditions of actual practice will be met, if the calculations are based upon the assumption that there are five hours full load and nineteen hours no load in transformers used for ordinary lighting purposes. With a given limit to the first cost, the losses should be so adjusted as to give a maximum all day efficiency. We might take a case where a transformer is supplying light to a private residence. Under this condition it would be loaded only a few hours each night. This will make the core losses which continues through the twenty-four hours very small, and the copper losses which continue but a few hours comparatively large. Thus we see it is advisable to design a transformer so as to have as small a power loss as possible in the iron, even though the design may envolve a considerable increase of power loss due to a copper resistance.

Too much copper in a transformer however, will give bad regulation results. In cases where a transformer is working all the time under a load, there should be a greater proportion of iron thus requireing less copper and giving less copper loss. We find that this is desirable in that a loaded transformer has usually a much greater copper loss than core loss. From a financial point of view it is advisable as iron is much less expensive than copper.

When a transformer is loaded there is always a certain falling off in secondary voltage, and when the load is thrown off,the voltage rises, the action being similar to that of alternators. As transformers are designed to deliver current at a certain voltage it is important that the regulation be as near perfect as possible. The deffinition of the regulation as authorized by the American Inatitute of Engineers is as follows; "In transformers the regulation is the ration of the r rise of the secondary terminal voltage from full load to no load (at constant impressed primary terminal) to the secondary full load voltage" This definition applies to constant frequency and non-inductive loads. If all the lines of force induced by the primary coils were available to the secondary the voltage regulation would be perfect. But part of the primary electro-motive force is used to overcome the resistance of the coils and part of the induced magnetism acts in such a way as to neutralize the impressed voltage. All the defects increase with load and thus the transformer regulation varies with the load. The regulation of a good transformer is much closer than that of an alternator, being seldom over three per cent on non-inductive load or six per cent for inductive load of power factor of .80 . Thus it is seen if good regulation is desired the inductive drop must be limited because it has a large effect on the terminal voltage if there is a lagging current.

In manycases it is difficult to measure voltage and regulation under actual load condition. This is especially true in high power, high voltage machines. Therefore the voltage regulation is predetermined from a simple short-circuit test. By this test the impedancesof the primary and secondary coils are measured.Then the resistances of the coils are measured by direct current. Having given the impedence and the resistance the reactance is easily found and used in the predetermination of regulation at different loads. In determining the reactance from the given impedance and resistance , the secondary resistance must be multiplied by the square of the ratio of transformation. This makes it equivalent to a simple circuit and from this equivalent reactance is found.

Following will be found data and curves taken from tests of a transformer,rated 110-55.

Efficiency Test

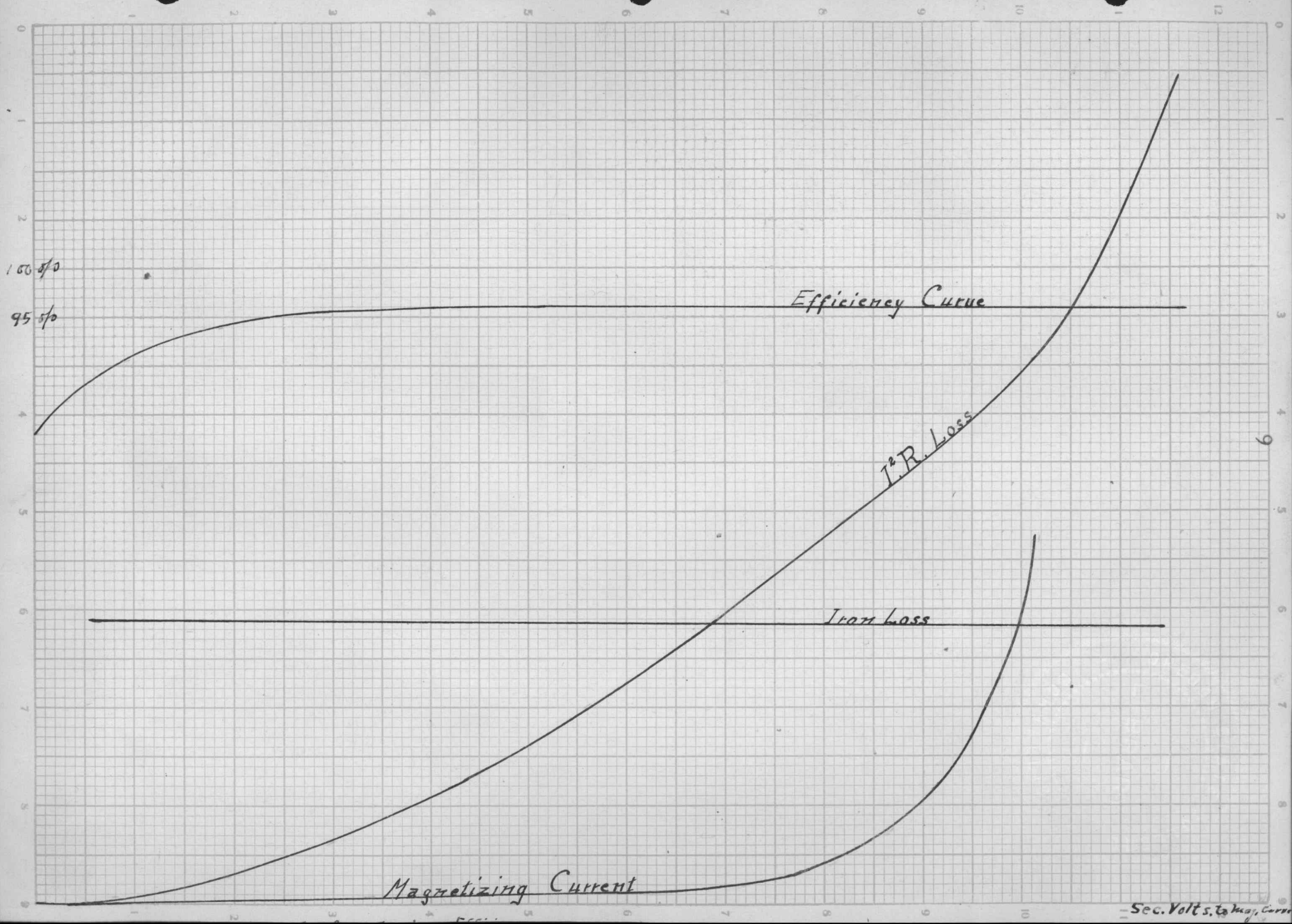
	Primary Amperes	Primary Volts	Secondary Amperes	Secondary Volts	Secondary Watts
(1)	.444	101.25	1	45	15
(2)	1.77	141.75	4	63	25
(3)	2.66	150.75	6	67	27.5
(4)	3.55	157.50	8	70	32
(5)	4.44	160.00	10	72	36
(6)	6.66	168.75	15	75	45
(7)	8.88	173.75	20	77	60
(8)	11.10	175.50	25	78	75
(9)	13.32	180.00	30	80	95

Ratio of transformation = 2.25 : 1

Resistance of primary coil = R = E/I =.146 ohms.

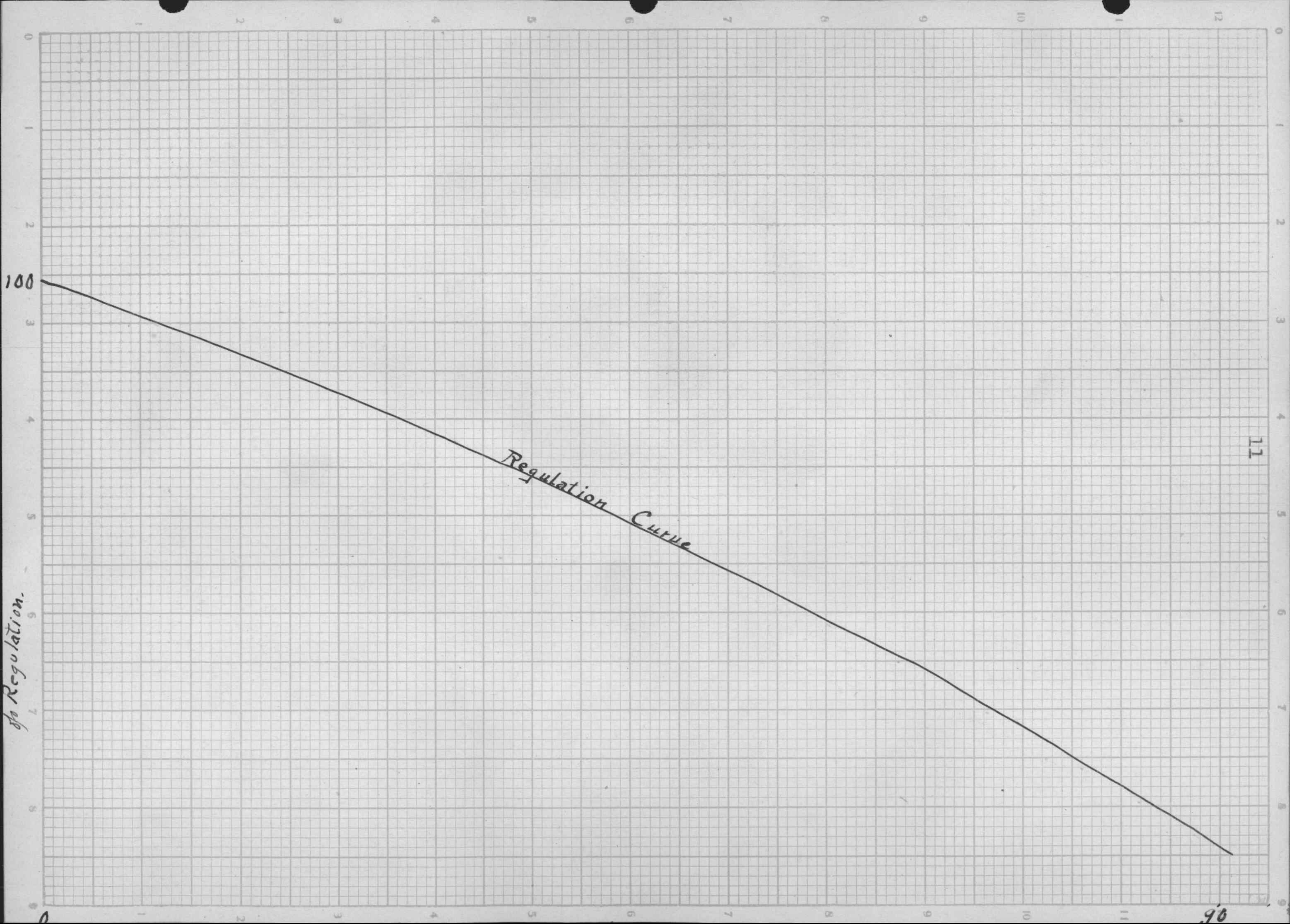
Resistance of secondary coil = R = E/I =.0458 ohms.

	Primary I^2R Loss	Secondary I^2R Loss	Iron Loss	Efficiency o/o
(1)	.0287	.0458	15	89.5
(2)	.465	.735	constant	92.5
(3)	1.035	1.65		94.5
(4)	1.84	2.94		95.
(5)	2.88	4.58		95.5
(6)	6.5	10.32		96.
(7)	11.53	18.32		96.
(8)	18.00	28.7		95.5
(9)	25.8	41.3		95.


100 %
95 %
Efficiency Curve
I²R. Loss
Iron Loss
Magnetizing Current
Sec. Volts to Mag. Curre

Regulation Test

Primary Amperes	Primary Volts	Secondary Amperes	Volts across Water Box
0	118.5	0.	118.5
2	117.5	4.5	117.
4	116.5	8.8	116.25
6	116.5	13.4	115.
8	116.5	17.4	114.5
10	115.5	22.	113.5
12	115.5	26.5	113.25
14	115.5	31.	111.5
16	114.5	35.75	110.5
18	113.5	40.	110.
20	113.	44.5	108.75
22	113.5	48.5	108.5
24	112.	53.	107.
26	112.	57.	106.5


100
Regulation Curve
% Regulation.
0
90
11