The Efficiency of Incandescent Lamps with Direct and Alternating Currents

This content has been downloaded from IOPscience. Please scroll down to see the full text.

1887 Proc. Phys. Soc. London 9 208

(<http://iopscience.iop.org/1478-7814/9/1/328>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 146.201.208.22

This content was downloaded on 02/10/2015 at 05:38

Please note that [terms and conditions apply](#).

In fact the magnetic resistance thus estimated is of linear dimension, and may be regarded as of linear scale in plans. If, therefore, this quantity be selected to be tabulated, the discussion of questions of design from a practical point of view is greatly facilitated, and the relations of the quantities involved are more easily followed and more simply expressed.

XXVIII. *The Efficiency of Incandescent Lamps with Direct and Alternating Currents.* By W. E. AYRTON and JOHN PERRY*

It is now well understood that in order to economically distribute power by means of electricity it is necessary to employ a high potential-difference, or P.D., between the mains and a small current flowing through them, while considerations of safety require that the P.D. between the leads in the houses shall not exceed 100 or 200 volts. Hence some system of converting a large P.D. and small current into a small P.D. and large current has to be employed; and the four systems of conversion that have hitherto been devised consist in the employment of:—1. Motor-Dynamos, 2. Accumulators, 3. Alternating Current-Transformers, 4. Direct Current-Transformers.

Of these four methods the third is the one that is most extensively utilized at the present time; indeed it is the only system of conversion that is at all extensively used, at any rate in this country. But in view of some direct current system of conversion also coming into common use, there arises a question of considerable importance to the consumer, viz. Is more light obtained with the same expenditure of power with direct or with alternating currents? And apart from considerations of the electric distribution of power on a large scale, the answer to this question is of importance in supplying one factor towards the decision as to the relative advantages and disadvantages of direct and alternating currents for detached installations.

Where the electric energy supplied to a consumer has been charged by meter, people have, as a rule, been content to measure only the number of coulombs supplied, ignoring

* Read February 25, 1888.

altogether any variation in the volts ; but as electricity *per se* apart from the P.D. is of no commercial value whatever, and therefore is unlike water apart from pressure, it is clear that in estimating the value of a supply of electric energy for lighting purposes we must measure the watts and not merely the current. The problem, therefore, that we have attempted to solve is whether a Board of Trade unit (1000 watt-hours) is more valuable for lighting by incandescent lamps when the current is direct or when the current is alternating.

For a complete solution of this problem we must ascertain not merely the "efficiency of the lamp" or the candles per watt with the two systems of supply, but also the life of the lamp, since the cost of lamp renewals may be as important a question for the consumer as the bill for electric power. Unfortunately, however, there does not exist, as far as we are aware, any accurate information as to the life of an incandescent lamp with various alternating P.Ds.; indeed the data at our disposal for the life of a lamp with various non-alternating P.Ds. is at most meagre. And if any Member of the Society can supply us with information regarding the life of some fixed type of incandescent lamp either with different direct P.Ds. or with different alternating P.Ds. we shall be grateful for the information, as it will furnish us with a further opportunity of using the method described in our paper read before this Society for deciding on "The most Economical Potential Difference to employ with Incandescent Lamps."*

For the present, therefore, we shall confine ourselves solely to the question of efficiency, and, as it is known that the efficiency of an incandescent lamp increases with the current passing through the lamp, it is clear that to obtain an accurate comparison of the efficiencies with direct and alternating currents, we must employ exactly the same current in both cases, or rather the same mean square of the current, for this will be most likely to develop the same rate of production of heat in the lamp, since this rate is proportional to the resistance into the mean square of the current, whether the current be direct or alternating, and whether or not there be

* Proc. Phys. Soc. vol. vii. p. 40.

self-induction in the circuit in which the heat is developed. We say will be most likely to develop the same rate of production of heat, since we must not assume without proof that for the same mean square of current the resistance of a carbon filament is the same whether the current be direct or alternating.

Some writers have stated that the current, as measured by an electro-dynamometer, required to be sent through an incandescent lamp when emitting a definite amount of light, had a different value when the current was an alternating one from what it had when the current was direct. This difference might be due either to a defect in the dynamometer measurement or to some variation in the light standard. If the wire with which a dynamometer is wound be thick, then the current-density may be far from uniform when the current is alternating; and on this account, as observed by Captain Cardew some years ago, a dynamometer might give different readings for different rates of alternations of the current, while an incandescent lamp in circuit with it remained equally bright. To avoid this possible cause of error the dynamometer, which was constructed by Messrs. Shepherd, Vignoles, and Wheatley (the three of the students of the Central Institution who carried out the investigation), was wound with much finer wire than would usually be employed in the construction of a dynamometer not required to read currents much below one ampere. The dynamometer was for that reason unnecessarily sensitive, and it required a fairly strong spring to control the motion of the suspended coil. This led to an unnecessary waste of energy in the dynamometer, but that was of no consequence in this investigation, as our object was to measure the mean square of the current most accurately, and not to satisfy the condition, which is of considerable importance in the design of commercial measuring-instruments, of wasting as little energy as possible in the instruments.

To the suspended coil of the dynamometer was attached a mirror, and the values of the deflections of the spot of light were determined by direct comparison with the simultaneous readings of an accurately calibrated magnifying spring-ammeter when various direct currents were successively sent through the circuit. The sensibility was such that a deflec-

tion of 400 scale-divisions was produced on a scale 68.88 inches away, for a current of 2.53 amperes, which corresponds with a deflection of 140 scale-divisions for 1.5 ampere,

and this was about the usual current passing through the dynamometer in the actual lamp experiments. The value of the current could, therefore, be accurately measured by this dynamometer, which is indicated by *D* in the figure, and by knowing what fraction of the current passing through the dynamometer *D* passed through the non-inductive voltmeter *V*, the current passing through the lamp is known.

Any error that might have arisen from a variation of the light-standard was eliminated by taking successive readings with a direct current produced by a Gramme-dynamo *G*, and with an alternating current produced by a Ferranti-dynamo *F*, the switches *S* and *s* being turned to 1, 1 in the first case and to 2, 2 in the second. The Gramme-dynamo *G* was also used to excite the field magnets of the Ferranti, a suitable current being obtained by a proper adjustment of the resistance *p*. By means of the resistances *q* and *t* the direct and alternating currents passing through the incandescent lamp *L* could be respectively varied; and it was found that if these resistances were so adjusted that the reading of the dynamometer *D* was the same in both cases, so also was the reading of the non-inductive voltmeter *V*.

It is known when power is supplied by means of an alternating current to a circuit of resistance r ohms and coefficient of self-induction l secohms that

$$\frac{\text{number of true watts}}{\text{number of measured watts}} = \frac{r\tau}{\sqrt{l^2\pi^2 + r^2\tau^2}},$$

where the measured watts are obtained by multiplying $\sqrt{A^2}$, the square root of the mean square of the amperes as measured by the dynamometer, by $\sqrt{V^2}$, the square root of the mean square of the volts as measured by the non-inductive voltmeter, and where τ is the time between one alternation and the next, or half a complete period. Therefore the

$$\text{number of true watts} = \frac{r\tau\sqrt{A^2V^2}}{\sqrt{l^2\pi^2 + r^2\tau^2}},$$

where in our case r and l are the resistance and coefficient of self-induction of the carbon filament of the lamp. In the first set of experiments a lamp with a looped filament was employed; but the experiments seemed to indicate that the value of l was not quite small enough to make the term $l^2\pi^2$ absolutely negligible, or else that there was some slight mutual induction between the dynamometer-coils and a small brass vessel containing oil, in which moved a damping-vane attached to the moving coil. The results were therefore discarded, and this vessel was replaced by one made of non-conducting material, and all metal near the dynamometer was as far as possible removed. The lamps subsequently employed were first one with a M-shaped filament, and another with a simple horseshoe-shaped filament, each possessing little self-induction.

The light was measured by comparison with a standard candle, the two being placed 130 centimetres apart on the photometer P, and a screen composed of two pieces of paraffin-wax W, with silvered paper between them, was adjusted until the two pieces of wax appeared equally bright, the comparison being first made when the screen was looked at through ruby-red glass and then through signal-green glass.

The following is a sample of the results obtained, a and b being the distances respectively of the screen from the incandescent lamp and from the standard candle,

TABLE I.

	$\sqrt{A^2}$	$\sqrt{V^2}$	Watts.	Green.			
				<i>a.</i>	<i>b.</i>	Candles.	Watts per Candle.
Ferranti.....	1.34	50	67	107.7	22.3	23.33	2.872
Gramme.....	1.34	50	67	105.8	22.2	23.52	2.848
Ferranti.....	1.34	50	67	107.9	22.1	23.74	2.823
Gramme.....	1.34	50	67	108	22	24.11	2.779
	$\sqrt{A^2}$	$\sqrt{V^2}$	Watts.	Red.			
				<i>a.</i>	<i>b.</i>	Candles.	Watts per Candle.
Ferranti.....	1.34	50	67	106.5	23.5	20.52	3.265
Gramme.....	1.34	50	67	106.4	23.6	20.34	3.295
Ferranti.....	1.34	50	67	106	24	19.51	3.435
Gramme.....	1.34	50	67	105.9	24.1	19.32	3.469

It will be observed that in the set of four successive observations given in Table I. for green light, the candle-power of the lamp appears to be steadily increasing, a result probably due to the brightness of the candle slowly diminishing; but although this would make the *absolute* determination of the efficiency of the incandescent lamp inexact, it introduces no error in the determination of the *relative* efficiencies of the lamp with direct and alternating currents, since every observation with the direct current was immediately followed by one with alternating current, so that the means of all the corresponding direct-current measurements may be safely compared with the means of all the alternating-current measurements. Similarly for this investigation it is unimportant whether the standard candle used on one day was slightly more or less bright than the standard candle used on the following day. Further, since for any two successive observations with the same coloured light with direct and with alternating current the screen was at practically the same distance from the lamp, the fact that the rays of light coming from the lamp made a somewhat different angle with the surface of the paraffin-wax from the angle made by the rays coming from the candle,

introduced no error in this investigation of *comparative* efficiencies, although it might very likely do so in an absolute determination of the efficiency of an incandescent lamp. In fact the simple device of successively taking observations with direct and with alternating currents throughout the whole investigation removed most of the objections that usually may be made against photometric determinations carried out with a candle as the standard of light.

Disregarding the experiments made with the lamp with the looped filament, for the reason given above, Table II. gives the summary of the results obtained; and the conclusion to be

TABLE II.—Mean Values.

Lamp.	No. of Experiments made.	$\sqrt{A^2}$	$\sqrt{V^2}$	Watts per Candle. White Light.				Time of an alternation, in seconds.
50 volt M-shaped filament.	20	1.25	50.5	Gramme. 3.053		Ferranti. 3.033		$\frac{1}{453}$
				Green Light. Gramme. Ferranti.		Red Light. Gramme. Ferranti.		
50 volt horseshoe-shaped filament	19	1.30	50.0	2.597	2.534	3.100	3.100	$\frac{1}{453}$
50 volt horseshoe-shaped filament	20	1.34	50.0	2.935	2.966	3.254	3.164	$\frac{1}{167}$
50 volt horseshoe-shaped filament	16	1.35	50.0	2.900	3.073	3.504	3.477	
Mean of the last three results				2.811	2.857	3.286	3.247	
Mean of all the 75 experiments				Gramme. 3.0490		Ferranti. 3.0497		

In all the experiments the plane of the filament was perpendicular to the screen. drawn from them is that although the watts per candle for green light are not quite the same for direct and for alternating currents, and although the volts per candle for red light are also not exactly the same for direct and alternating, still the difference between the results for the same colour is so small that it may be put down to experimental errors; and this, combined with the fact that the mean of all the 75 experiments gives practically the same number of watts per candle for both direct and alternating currents, leads to the practical certainty that *the efficiency of an incandescent lamp is the same for both direct and alternating currents.*