ELECTRO-MOTORS.

THEIR POWER AND RETURN.

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The transmission of force from a distance, electric ploughing, the electric railroad, etc., have made electric motors and the conditions of maximum work and maximum return, quite the order of the day. In a previous article on the available force in batteries, we have determined, for the most usual forms, the quantity of energy that could be furnished by a certain number of elements in an external circuit of proper resistance, supposing no polarization and without variation of the internal resistance.

Is this maximum of available work entirely convertible into effective work? It is not, and we will show how this maximum should be reduced when a given electric energy is to be transformed into mechanical force.

Let us suppose, for instance, in numbers, which always strike the attention more than formulas, that we have a source of electricity of 100 volts, with an internal resistance of 1 ohm. It would be easy to realize the conditions by employing an electro-dynamic machine, separately excited, or 100 very large Bunsen cups, arranged for tension in 2 parallel series of 50 each. Putting into the circuit an external resistance equal to the internal, and supposing no polarization to exist and no change in the internal resistance, we obtain as elements for the electric circulation:

E.—Electro motive force $=$ 100 volts.
r.— Internal resistance $=$ 1 ohm.
R.—Exterior resistance $=$ 1 ohm.
(r + R)—Total resistance $=$ 2 ohms.

$$Q.\text{—Quantity } \frac{E}{r+R} = \frac{100}{1+1} = 50 \text{ webers.}$$

In these conditions we know that we have in the external circuit the maximum of available work, as deduced from the formula of Joule:

$$W = 10\ Q^2R \text{ meg-ergs} \qquad (a)$$

$$\text{or } W = \frac{Q^2R}{9.81} \text{ kilogram-meters} \qquad (b)$$

In the case before us we have:

$$W = 10 \times 50^2 \times 1 = 25{,}000 \text{ meg-ergs} \quad (1)$$

What can we do with this available electric work? If we make it traverse an inert wire it will heat it. All the electric energy will be transformed into heat, and in this wire will be developed a certain number of calorics C, per second:

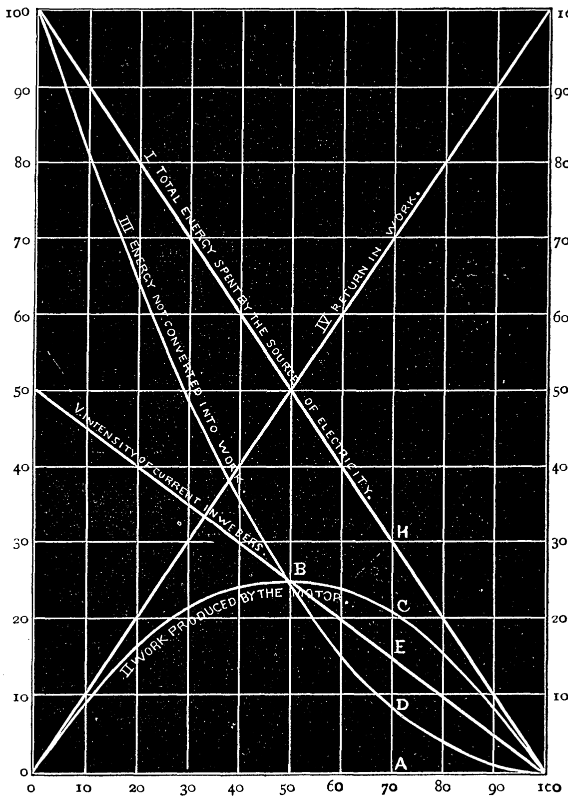
$$C = \frac{Q^2R}{9.81} \times \frac{1}{A}. \qquad (c)$$

A being the mechanical equivalent of heat 424.

Let us substitute for the inert resistance of a wire, an electro-motor of equal resistance with the wire, say 1 ohm in this particular case. Let us suppose this motor to be one of Gramme's magneto-electric machines, and that the resistance of the armature is equal to 1 ohm. If we put a break on the armature to prevent it turning under the influence of the passing current, we will not have any of the original conditions changed; the wire of the armature will be heated by the current, and a number of calorics C will be produced equal to that developed in the wire. Now let us make the armature turn under the action of the electric current. The rotary motion of this armature will develop a certain electro-motive force E′, inverse to that emanating from the source of electricity E, varying with the speed of the motor. It results in a diminution of the current, and can be expressed at each instant by the formula:

$$Q^1 = \frac{E - E'}{r + R}. \quad (d)$$

Hence the rotation of the motor diminishes the intensity of the current (and consequently the work of the motor) if a machine is employed as a source of electricity, or the consumption of zinc, if you employ a battery. The diagram shows how the different elements vary when the speed of the motor varies from zero (where the work developed is null) to a velocity such that the opposing electro-motive force E, which it develops, becomes equal to the electro-motive force of the source. It is seen that the energy expended by the source of electricity diminishes from the time the motor begins to turn (curve I.); similarly, the intensity of the current (curve V.) diminishes to zero when E and E′ become equal. Curve II. represents the work developed by the motor at different speeds. Let us suppose these speeds are proportional to the electro-motive forces—a hypothesis easily verified in a well constructed magneto-electric machine—then we see, by the diagram, an augmentation of the work produced, up to a point where the speed of the motor becomes 50. At this moment the work done is at a maximum, and represents but 50 per cent. of the work expended by the source of electricity. The energy converted into work (curve III.) is equal to what is unconverted (curve II.). If the speed augments beyond this point the work produced (curve II.) diminishes, but the return augments (curve IV.).



The work produced and the return are hence perfectly distinct things which are too often confounded. There is no impossibility in making the motor return 80 per cent. of the work expended by the source of electricity, on condition you do not make this source produce all the work which it can furnish. When, at the limit, the work produced becomes null, the return becomes equal to 1. The same conclusion is arrived at on comparing curves I. and II. It is thus seen that energy not converted into work, diminishes more rapidly than the total energy expended by the source of electricity. When the motor is at rest, the work is zero, all energy being transformed into heat. When $E' = \frac{E}{2}$, the diagram shows that the work is equal to the loss; curves II. and III. cut each other at B and the return is 50 per cent. Several consequences result from this. If you wish to obtain the *greatest* results from any given source of electricity, the electro-motor, turning at normal speed, must be so arranged as to develop a counter electro-motive force equal to the half of the original source. If the *best* results are wanted greater speed is required, by which a return in work is gained with a corresponding loss in the quantity of work produced.

Curves III. and IV. show why an electro-motor heats more when stopped than when turning at a certain speed; the intensity of the current is greater in the first case than in the second, the electro-energy not converted into work, diminishing with increase of speed, is converted into heat in the conducting wire. The two causes are correlative.

Let us cite a case having peculiar bearing on the transmission of power at a distance by electro motors, for instance, in electric traction on railways. Suppose our motor to turn at a normal speed developing a force of 70 volts. In this condition the work produced is represented (on the diagram) by A C, the work expended on the source of electric supply by A H, and the return is 0.70. If the existing work is augmented (by putting on a brake, for instance,) it will diminish the speed of the motor; but the curve II. shows that by this very diminuition of speed the work produced by the motor augments, and a new state of equilibrium is produced very close to the first. If, on the other hand, the resisting work diminishes, the speed will augment, and the work produced will diminish. Hence we see that the work of the motor augments with the resistance, and diminishes as well with it, a most favorable condition for regulating speed and maintaining it within certain bounds not far apart. This automatic governing is not to be found in any other motor. In the latter, special apparatus has to be called into play, as in the well-known case of steam.

This statement of the theoretical conditions affecting the functions of an electro-motor supplied from a given source, shows between what limits its different elements can be made to vary. The numbers which we have given for the maximum of work in batteries, as well as those given by M. Reynier in his work on the pile, have regard only to the total available energy in the external circuit, without consideration of the manner in which this energy is ultimately used. If, as in the above hypothetical case, it is desired to transform this energy into work of an electro motor, but half of the maximum work can be obtained. If, on the other hand, it is proposed to get the greatest *sum* of work in an indefinite time, the return can be augmented and collected up to as high as 80 and 90 per cent. of the energy represented by the expenditure of zinc in the battery, but then the pile does not produce its *maximum of work*.

The influences of the external resistances remain to be examined, such as are presented in transmitting force at a distance; also the resistance of the motor itself, and the practical returns obtained in certain special cases with motors of determinate type.

We will take occasion to recur to this subject after practical experience has had the last word. It is always well, however, to recall theoretical results, which never being altogether attained in practice, have an advantage in setting exact limits to our knowledge of what can be obtained from any given source of electrical supply; and. while destroying some illusions, proving some statements, which till now, have seemed too adventurous. (*La Lumière Electrique*, Aug. 7th.)

MULTIPLE SPECTRA.*

II.

I concluded my last article under the above heading with a reference to the case of carbon, and gave the results successively arrived at by Attfield, Morren, Watts, and others; these went to show that besides the line-spectrum of carbon mapped by Angström there exists a fluted spectrum of this substance.

Now comes my own personal connection with this matter.

In the year 1871,[1] I communicated to the Royal Society a paper in which the conclusion was drawn that the vapor of carbon was present in the solar atmosphere.

This conclusion was founded upon the reversal in the solar spectrum of a set of flutings in the ultra-violet.[2] The conclusion that these flutings were due to the vapor of carbon, and not to any compound of carbon, was founded upon experiments similar to those employed in the researches of Attfield and Watts, who showed that the other almost exactly similar sets of flutings in the visible part of the spectrum were seen when several different compounds of carbon were exposed to the action of heat and electricity. In my photographs the ultra violet flutings appeared under conditions in which carbon was the only constant, and it seemed therefore reasonable to assume that the flutings were due to carbon itself, and not to any compound of carbon, and this not alone from the previous work done in the special case of carbon, but from that which had shown that the fluted spectra of sulphur, nitrogen, and so forth, were really due to these "elementary" substances.

Professors Liveing and Dewar have recently on several occasions called this result in question. Professor Dewar, in a paper received by the Royal Society on January 8, 1880, writes as follows:

"The almost impossible problem of eliminating hydrogen from masses of carbon, such as can be employed in experiments of this kind, prove conclusively that the inference drawn by Mr. Lockyer, as to the elementary character of the so-called carbon spectrum from an examination of the arc in dry chlorine, cannot be regarded as satisfactory, *seeing that undoubtedly hydrogen was present in the carbon* used as the poles.

Subsequently, in a paper received by the Royal Society, on February 2, Messrs. Liveing and Dewar wrote as follows:

"Mr. Lockyer (*Proc. Roy. Soc.*, vol. xxvii. p. 308) has recently[3] obtained a photograph of the arc in chlorine, which shows the series of fluted bands in the ultra-violet, on the strength of which he throws over the conclusion of Angström and Thalèn, and draws inferences as to the existence of carbon vapor above the chromosphere in the coronal atmosphere of the sun, which, if true, would be contrary to all we know of the properties of carbon. We cannot help thinking that *these bands were due to the presence of a small quantity of nitrogen.*"

It will be seen that on January 8 Mr. Dewar alone attributed the flutings to a hydrocarbon, while on February 2 Mr. Dewar, associated with Mr. Liveing, attributed them to a nitrocarbon.

In fact in the latter paper Messrs. Liveing and Dewar published experiments on the spectra of various carbon compounds, and from their observations they have drawn the conclusion that the set of flutings which I have shown to be reversed in the solar spectrum is really due to *cyanogen*, and that certain other sets of flutings shown by Attfield and Watts to be due to carbon are really due to hydrocarbon.

As Messrs. Liveing and Dewar do not controvert the very definite conclusions arrived at by Attfield, Morren, Watts, and others, I can only presume that they took for granted that all the experimental work performed by these men of science was tainted by the presence of impurities, and that it was impossible to avoid them. I therefore thought it desirable to go over the ground again, modifying the experimental method so as to demonstrate the absence of impurities. Indeed I have started upon a research which will require some time to complete. Still, in the meantime, I have submitted to the notice of the Royal Society some results which I have obtained, which I think settle the whole question, and it is the more important to settle it as Messrs. Liveing and Dewar have already based upon their conclusions theoretical views which appear to me likely to mislead, and which I consider to have long been shown to be erroneous. To these results I shall now refer in this place.

The tube with which I have experimented is shown in Fig. 1: A and B are platinum wires for passing the spark inside the tube; E is a small tube into which carbon tetrachloride was introduced; it was drawn out to a long narrow orifice to prevent the rapid evaporation of the liquid during the exhaustion of the tube. The tube was bent upwards and a bulb blown at C in order that the spark might be examined with the tube end-on, as its found that after the spark has passed for some time a deposit is formed on the sides of the bulb immediately surrounding the platinums, thus obstructing the light. After a vacuum had been obtained the tube was allowed to remain on the Sprengel pump, to which it was attached by a mercury joint for the purpose of obtaining a vacuum for a long time, in order that the last traces of air and moisture might be expelled by the slow evaporation of the liquid.

* Continued from p. 29.

[1] *Proc. R. S.* No. 187, 1878.

[2] The approximate wave-length of the brightest member on the least refrangable edge is 3881.0.

[3] That is, in 1878.—J. N. L.