ON THE PYROMAGNETIC DYNAMO—A MACHINE FOR PRODUCING ELECTRICITY DIRECTLY FROM FUEL.*

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The production of electricity directly from coal is a problem which has occupied the closest attention of the ablest inventors for many years. Could the enormous energy latent in coal be made to appear as electric energy by means of a simple transforming apparatus which accomplishes its results with reasonable economy, it will be conceded probably that the mechanical methods of the entire world would be revolutionized thereby, and that another of those grand steps of progress would be taken of which the nineteenth century so justly boasts.

The simple production of a potential difference by means of heat is as old as Seebeck and Melloni. The science of thermo-electricity thus originated has been developed by Becquerel, by Peltier, by Thomson, and by Tait, and the thermo-batteries of Clamond and of Noe have found many important practical uses. The results already attained in these generators have stimulated research marvelously, and many investigators have believed that in this direction lay the philosopher's stone. Our fellow member Moses G. Farmer worked long and assiduously in this field, producing, it is believed, the most satisfactory results as regards economy which have ever been obtained. But even these results were not very encouraging. He never succeeded in converting one per cent of the energy of the coal into electric energy. Quite recently, Lord Rayleigh has discussed, with his well-known ability, the law of efficiency of the thermo battery from the standpoint of the second law of thermodynamics. And he concludes that for a copper-iron couple, working between the extreme limits of temperature possible for these metals, a conversion of not more than one three-hundredth part of the coal energy can be hoped for. While therefore as a heat engine the thermo cell appears to follow precisely the law of Carnot, and hence may have a theoretical maximum efficiency equal to that of the reversible engine of this eminent philosopher, yet in practice its efficiency falls very far below this theoretical maximum.

It therefore follows that if the result hoped for is to be attained at all, it must obviously be looked for in some other direction than in that of the thermo cell. In considering the matter, another line of investigation suggested itself to me, the results of which I have the honor now to submit to my fellow members of the Physical Section. It has long been known that the magnetism of the magnetic metals, and especially of iron, cobalt, and nickel, is markedly affected by heat. According to Becquerel, nickel loses its power of being magnetized at 400°, iron at a cherry-red heat, and cobalt at a white heat. Since, whenever a magnetic field varies in strength in the vicinity of a conductor, a current is generated in that conductor, it occurred to me that by placing an iron core in a magnetic circuit and by varying the magnetizability of that core, by varying its temperature, it would be possible to generate a current in a coil of wire surrounding this core. This idea constitutes the essential feature of the new generator, which therefore I have called a pyromagnetic generator of electricity.

The principle of utilizing the variation of magnetizability by heat as the basis of electric machines, though clearly applicable to generators, was first applied to the construction of a simple form of heat engine, which I have called a pyromagnetic motor. A description of this motor will help us to understand the generator subsequently constructed.

Suppose a permanent magnet, having a bundle of small tubes made of thin iron placed between its poles, and capable of rotation about an axis perpendicular to the plane of the magnet, after the fashion of an armature. Suppose, farther, that by suitable means, such as a blast or a draught, hot air can be made to pass through these tubes so as to raise them to redness. Suppose that by a flat screen symmetrically placed across the face of this bundle of tubes and covering one-half of them, access of the heated air to the tubes beneath it is prevented. Then it follows that if this screen be so adjusted that its ends are equidistant from the two legs of the magnet, the bundle of tubes will not rotate about the axis, since the cooler and magnetic portions of the tube bundle (*i. e.*, those beneath the screen) will be equidistant from the poles, and will be equally attracted on the two sides. But if the screen be turned about the axis of rotation so that one of its ends is nearer one of the poles and the other nearer the other, then rotation of the bundle will ensue, since the portion under the screen, which is cooler and therefore magnetizable, is continually more strongly attracted than the other and heated portion. This device acts, therefore, as a pyromagnetic motor, the heat now passing through the tubes in such a way as to produce a dissymmetry in the lines of force of the iron field, the rotation being due to the effort to make these symmetrical. The guard plate in this case has an action analogous to that of the commutator in an ordinary armature. The first experimental motor constructed on this principle was heated by means of two small Bunsen burners, arranged with an air blast, and it developed about 700 foot pounds per minute. A second and larger motor is now about finished, which will weigh nearly 1,500 pounds, and is expected to develop about three horse power. In both these machines electro-magnets are used in place of permanent magnets, the current to energize them being derived from an external source. In the latter machine, the air for the combustion is first forced through the tubes to aid in cooling them, and then goes into the furnace at a high temperature.

The earliest experiments in the direction of the pyromagnetic production of electricity were made with a very simple apparatus, consisting of a charged electro-magnet, having a tube of thin iron passing through its cores near their outer ends, a coil of wire being wound round this tube, and including an ordinary sounder delicately adjusted, in its circuit. The tube beneath the coil was covered with asbestos paper. After heating the tube to redness by a gas blast directed into it at one end, a jet of cold air was suddenly substituted for the flame; the sounder at once closed, showing that the change in the magnetizability of the iron had varied the distribution of the lines of force within the coil, and thus had produced a current of electricity in this closed circuit.

The construction of a machine of sufficient size to demonstrate the feasibility of producing continuous currents on the large scale in this way was at once begun, and has only just been completed. The new machine consists of eight distinct elements, each the equivalent of the device already mentioned, consisting of the two legs of an electro-magnet somewhat far apart (twelve inches actually), having at one end the ordinary yoke, and at the other a roll of corrugated sheet iron, 0·005 inch thick, called an interstitial armature; this armature having a coil of wire wound upon it, and separated from direct contact by means of asbestos paper. The eight elements are arranged radially about a common center, and are equidistant, the eight interstitial armatures passing, in fact, through the iron disks which constitute the common pole pieces of all the electro-magnets. The coils wound upon the interstitial armatures are connected directly in series, the whole forming a closed circuit. Through the center of these disks a hollow vertical shaft passes, carrying at its lower end a semicircular plate of fire clay called a guard plate, which, when the shaft is turned, revolves close to the lower ends of the sheet iron armatures, and screens off half of them from the access of heat from below. The shaft carries a cylinder of insulating material, having metallic contact pieces let into it on opposite sides, the line joining them being parallel to the straight edge of the guard plate. Upon this cylinder eight springs press, each of these springs being connected to the wire of the closed circuit above mentioned midway between the coils. The length of the metallic segment is so proportioned that the following spring touches it just as the preceding one leaves it. The springs themselves are so adjusted that each of them comes into contact with its metallic segment just as the preceding coil of the pair to which it is connected is uncovered by the rotation of the guard plate. Upon the same shaft, and above the cylinder just mentioned, a pair of metallic rings are placed, insulated from the shaft, to each of which one of the metallic segments is connected. Brushes pressing upon these rings take off the current produced by the generator.

The entire machine now described is placed upon the top of any suitable furnace, fed by a blast, so that the products of combustion are forced up through those interstitial armatures which are not covered by the guard plate, and raise them to a high temperature. The field magnets when charged magnetize of course only those interstitial armatures which are cold, *i. e.*, those beneath the guard plate. On rotating this plate, the interstitial armatures are successively uncovered on the one side and covered on the other; so that continually during the motion, four of the eight armatures are losing heat and the other four are gaining heat. But those which are losing heat are gaining magnetism, and *vice versa*. Hence, while currents are generated in all the armature coils, since in all the magnetism is varying, the current in the coils beneath the guard plate will be in one direction, while that in the coil exposed to the fire will be in the other. Moreover, whenever an armature passes out from under the guard plate, its condition at once changes; from losing heat and gaining magnetism, it begins to gain heat and to lose magnetism. Hence, at this instant, the current in its coil is reversed; and consequently the line connecting this coil with the one opposite to it constitutes the neutral line or line of commutation, precisely as in the ordinary dynamo. Indeed, the action of the interstitial armature coils of the pyromagnetic dynamo resembles strongly that of the ordinary armature coils of the Gramme ring, not only in the manner of connecting them together, but also in their functions; the change of direction in the current as the magnetism of the field changes sign, in the latter case corresponding closely to the change of current in the former case due to the direction of the temperature change. But it will be observed that while in the Gramme ring the loops between the armature coils are connected to commutator segments equal in number to that of the coils, upon which commutator two brushes press, in the pyromagnetic dynamo the loops between the armature coils are connected to an equal number of brushes (in this case eight), while the commutator segments are only two in number. So that the functions of the commutator and the brushes in this generator are in a certain sense reversed as compared with the ordinary dynamo.

The potential difference developed by this dynamo will obviously depend (1) upon the number of turns of wire on the armature coils, (2) upon the temperature difference in working, (3) upon the rate of temperature variation, and (4) upon the proximity of the maximum point of effect. No advantage will be gained, of course, by raising the temperature of the interstitial armature above the point at which its magnetizability is practically zero, nor will it be advantageous, on the other hand, to cool it below the point where its magnetism is practically a maximum. The points of temperature, therefore, between which, for any given magnetic metal, it is most desirable to work, can be easily determined by an inspection of the curve showing the relations between heat and magnetism for this particular metal. Thus the points of temperature at which the magnetizability is practically zero, as above stated, are a white heat for cobalt, a bright red for iron, and 400° for nickel. On the other hand, while at ordinary temperatures iron has a maximum intensity of magnetization represented by 1,390, its intensity at 220° is 1,360, and hence no commercial advantage is gained by cooling the iron below this temperature. Nickel, however, whose maximum intensity of magnetization at ordinary temperatures is 800, has an intensity of only 380 at 220°. Hence while this metal requires a lower maximum temperature, it also requires a lower minimum one, but it may be worked with much less heat. The rate of the temperature variation is determined by the rapidity with which the guard plate revolves; and this in its turn is dependent upon the rapidity with which the interstitial armature can be cooled and heated. That it may take up and lose heat readily, the sheet iron of which it is made is very thin (only 0·005 inch thick, even when its durability is increased by enameling or nickeling), it is corrugated and rolled up so as to expose a large surface (about 60 square feet for the eight armatures), and hot and cold air are alternately forced through the armature. Experiments already made show that the guard plate can probably be made to revolve 120 times a minute. Since the potential difference is proportional to the number of lines of force cut per second, it is evident that by doubling the speed of rotation twice as many lines of force would flow across the generating coils per second, and the output of energy would be quadrupled. Exactly what thickness of metal is the most suitable for the purpose, what the relative volume occupied by metal and by air space in the interstitial armature should be, what is the best diameter for this armature, or even the best metal, what the best limits of temperature, and what the best speed of rotation to produce the maximum potential difference—all these are questions which must be decided by experiments made upon the generator itself.

The results thus far obtained lead to the conclusion that the economy of production of electric energy from fuel by the pyromagnetic dynamo will be at least equal to and probably greater than that of any of the methods in present use. But the actual output of the dynamo will be less than that of an ordinary dynamo of the same weight. To furnish thirty sixteen-candle lights in a dwelling house would probably require a pyromagnetic generator weighing two or three tons. Since, however, the new dynamo will not interfere with using the excess of energy of the coal for warming the house itself, and since there is no attendance required to keep it running, there would seem to be already a large field of usefulness for it. Moreover, by using the regenerative principle in connection with it, great improvement may be made in its capacity, and its practical utility may very probably equal the interesting scientific principles which it embodies.

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Oil the Waves.

In a pamphlet issued lately by the U. S. Hydrographic Office, Lieut. Underwood says that mineral oils are not so effective for use at sea as vegetable or animal. A comparatively small amount of the right kind of oil, say two quarts per hour, properly used, is sufficient, he asserts, to prevent much damage, both to vessels and to small boats, in heavy seas. The greatest result from oil is obtained in deep water. In a surf, or where water is breaking on a bar, the effect is not so certain; but even in this case oil may be of benefit, and its use is recommended by Lieut. Underwood. He advises that, when an attempt is about to be made to board a wreck, the approaching vessel should use the oil after running as close as possible under the lee of the wreck. The wreck will soon drift into the oil, and then a boat may be sent alongside of her.