COUNTER ELECTROMOTIVE FORCE IN THE ALUMINUM RECTIFIER

BY

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A DISSERTATION

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I. INTRODUCTION.

THE anomalous action of aluminum in the electrolytic cell was first discovered by Wheatstone in 1855. Soon after this, Buff found that an electrolytic cell one electrode of which was aluminum would rectify the alternating current. Among the other men who have been interested in this cell may be mentioned Ducretet,[1] Hutin and Leblanc,[2] Montpellier,[3] Nodon,[4] Guthe,[5] Greene,[6] and Schulze.[7] The latter has perhaps done the largest amount of work of any. His articles have appeared from time to time in a number of magazines.

The earlier experimenters with this cell confined themselves to the study of aluminum but later investigation[7] has shown that many other metals possess this same property to a greater or less degree. Among these may be mentioned iron, nickle, cobalt, magnesium, cadmium, tin, bismuth, zirconium, tantalum, etc.

A great many electrolytes may be used in the rectifier. The most commonly used are the alums, phosphates, and carbonates; however Greatz and Pollak[8] have shown that any electrolyte which will liberate oxygen on electrolysis may be used more or less satisfactorily.

It has been found that the ability of the cell to rectify alternating current depends upon the current density at the aluminum anode,[9] the inductance and resistance of the circuit,[10] and its temperature.[11] The cell works best when the current density is high and the inductance, resistance, and temperature are low.

1 Comptes Rendus, Vol. 80, p. 280.
2 French Patents, No. 215945.
3 Electrician, Vol. 22, p. 17.
4 Comptes Rendus, Vol. 136, p. 445.
5 PHYS. REV., Vol. 15, p. 327.
6 PHYS. REV., Vol. 3, series 2, p. 264.
7 Zeitschr. Elektrochem., Vol. 14, p. 333.
8 Elektrotechnische Zeitschr., Vol. 25, p. 359.
9 Elektrotechn. Zeitschr., Vol. 21, p. 913.
10 Ann. der Physik, Vol. 39, p. 976.
11 Zeitschr. Elektrochem., Vol. 14, p. 333.

Two prominent theories have been advanced to explain the action of this cell. The earlier theory, known as *the solid film theory*, ascribes this action to the electrolytic deposition and decomposition of a solid film of some oxide or hydroxide of aluminum on the aluminum anode. The deposition takes place while the current flows in at the aluminum and, being a high resistance material, the film soon grows to a thickness which shuts off the current in that direction. The decomposition takes place when the current is in the opposite direction and permits the current to flow unimpeded from the electrolyte to the electrode.

In 1902 Guthe[1] first gave us the later theory, known as *the gas film theory*. This theory ascribes the action to a film of oxygen gas which is spread over the solid layer. The free electrons of the metal are forced through the gas film by the very high potential gradient with very little difficulty, when the aluminum is the cathode, but when the current reverses, and the aluminum is the anode, no such thing can take place because there are no free electrons in the electrolyte. Instead, the current must be carried through the film by the ions of the electrolyte and these being relatively large as compared to the electrons are with difficulty forced through.

It has been known for a great many years that the aluminum cell acts to a certain extent like a condenser. Schulze[2] states that a cell 40 $\times$ 40 $\times$ 40 cm. with both plates of aluminum had a capacity of 5,000 mfd. on 160 volts alternating current of a frequency of 50 cycles per second. It was possible, he states, to take an alternating current of 250 amperes through this cell. But one must not go too far in likening this cell to an ordinary leaking condenser as Greene[3] has shown.

This investigation was undertaken to determine if a more careful study of the counter electromotive force, which is produced when current enters at the aluminum, would throw some light on the action of the cell as a condenser and also on the theories advanced.

The cell used was composed of a lead plate with an area of approximately 90 sq. cm. and an aluminum wire .258 cm. in diameter and 10 cm. in length, immersed in a saturated solution of sodium phosphate. The aluminum wire was tested and found to contain .27 per cent. iron and some silicon in the form of silicates. It is about 99 per cent. pure. The lead is the same grade as that used in the chemistry department in qualitative experiments and is believed to be as pure as the aluminum. Both electrodes are heavily coated with a good grade of sealing wax where

[1] PHYS. REV., Vol. 15, p. 327.

[2] Zeitschr. Elektrochem., Vol. 14, p. 333.

[3] PHYS. REV., Vol. 3, series 2, p. 264.

they emerge from the solution to eliminate surface effects which were found to be present when the electrodes were not coated.

II. Experimental Work.

As a preliminary study, a potentiometer method was devised for the measurement of the counter electromotive force. The cell was placed directly across the storage battery terminals for a time with the aluminum as anode and then the counter electromotive force, after a certain period of open circuit, was compared directly with the storage battery voltage. This period of open circuit was adjusted and measured by means of the disk described in the following method. Although this potentiometer method gives very accurate measurements of time of open circuit and of counter electromotive force, it is too slow to give the desired results.

Since the time for taking the readings by the former method could not be decreased, the oscillographic method was devised. This method enables one to take a complete set of readings in about one second. This eliminates to a large degree the objection to the former method and also enables one to get readings for much shorter periods of closed circuit.

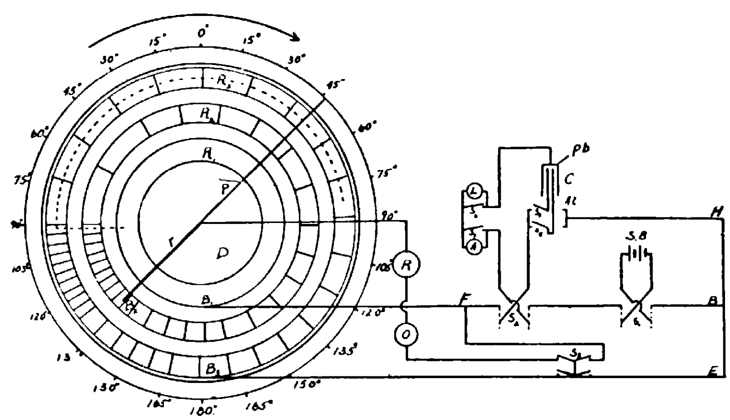

Fig. 1.

The diagram for the arrangement of apparatus is shown in Fig. 1. In this method the same disk was used as before with the same brush contacts and the same electrical connections on the disk. This disk is shown as *D*. It was designed for this work and made in the engineering shops of the University of Michigan. It is a solid, hard rubber disk of approximately 31 cm. radius. Firmly screwed to this disk are three concentric rings of brass. The inner ring R_1 has an inner radius of 12 cm. and an outer radius of 16 cm. It is made in one solid piece. The second ring R_2 has an inner radius of 19 cm. and an outer radius of 23 cm. It is divided into sectors ranging in magnitude from 5 degrees to