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Dry-Disc Rectifiers

By the Engineering Department, Aerovox Corporation

THE dry-disc type rectifier owes its wide acceptance to simplicity, absence of electron tubes and all moving parts, silent operation, and in several instances, unlimited life. Since there are no intermittently-operated contacts in this device, no arcs are present to wear away mechanical parts or to set up radio interference. Presenting an almost pure resistance load, the dry-disc rectifier responds instantly when an alternating voltage is applied. Transients are notably absent in its operation.

Applications of the dry-disc rectifier have increased steadily since its chance discovery several years ago when Grohndahl and Geiger of Union Switch & Signal Co., investigating corrosion of copper switches, observed that current flows through an oxide film on copper more readily in one direction than in the other.

At present, the dry-disc type rectifier is regularly employed in a number of applications which include rectification of alternating currents for indicating meters, battery charging, circuit-breaker solenoid operation, electroplating, radio speaker field excitation, electron tube filament operation, fire alarm operation, supply of direct currents for telephone and telegraph circuits, energizing relay coils, operation of industrial control devices, actuation of time clocks and signal bells, cathodic protection of underground pipe lines and cables, and the supplying of power for arc welders and motion picture carbon arcs.

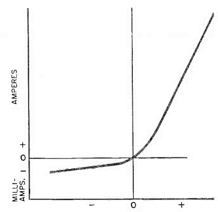
This type of rectifier is usually encountered in low voltage, high-current service. In each of its applications, it reduces maintenance expense, through its unique features, and very often needs no replacement. It is well suited for all unattended services.

THEORY OF OPERATION

In a dry-disc rectifier, rectification occurs at the interface of two dissimilar conducting materials. The phenomenon is not completely explained at this time. The couple formed by the opposite materials presents a high resistance to input voltage of one polarity and a considerably lower resistance when the applied voltage is of opposite polarity. As a result, there exists a high ratio of current flowing through the couple in one direction to that flowing through it in the reverse direction.

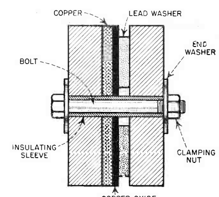
Current in one direction may thus attain a strength of several amperes, while that in the opposite direction (termed "back", "blocking", "inverse", or "leakage" current) is limited to a few milliamperes. Equal amounts of current will pass in both directions only when the breakdown voltage of the rectifier, its operating temperature, or both, are exceeded.

A curve showing dry-disc rectifier action is given in Figure 1. Positive voltage values correspond to the low-resistance direction of the rectifier; negative values to the high-resistance direction. From this curve, it is seen that the voltage approaches zero as these two resistances approach a common value. With increasing voltage input, the high resistance increases and the low resistance decreases, both rapidly. After reaching a certain point,



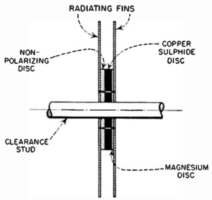
VOLTAGE-CURRENT CHARACTERISTIC OF DRY-DISC RECTIFIER

Figure 1



SINGLE ELEMENT OF COPPER-OXIDE RECTIFIER

Figure 2



SINGLE ELEMENT OF MAGNESIUM-COPPER SULPHIDE RECTIFIER
Figure 3

depending upon the type of rectifier and somewhat upon its dimensions, further changes in the high resistance take place much more slowly, while the low resistance continues to drop.

The *rectification ratio*, closely related to rectifier efficiency, varies with the magnitude of the applied voltage, and is the ratio of this voltage at any point to the corresponding low resistance value at the same point.

Breakdowns due to exceeding the normal voltage rating or operating temperature of some dry-disc rectifiers are usually temporary, the selenium and magnesium-copper sulphide units tending to restore themselves when normal operating conditions are resumed.

Current depends upon the surface area of the active materials. Dry-disc rectifiers may be supplied for very high current output. The maximum permissible current density per rectifier unit depends upon the amount of ventilation provided either by fan draft or by means of ventilating fins incorporated into the element structure. Fins will handle cooling adequately at current densities up to 2 amperes per square inch when forced draft is provided.

Dry-disc rectifiers range in size from the tiny units, approximately 1/32-inch square in the smallest size, used in connection with movable-coil direct current instruments to large models capable of supplying several thousand amperes at low voltage.

Dry-disc rectifier elements are commonly assembled as alternate discs or plates of metallic materials on a bolt or threaded stud which is insulated from the active members by a sleeve of non-conducting material (See Figures 2, 3, and 5). The entire assembly may be clamped tightly, by means of end nuts and spring washers, to insure permanent and efficient electrical contact.

TYPES

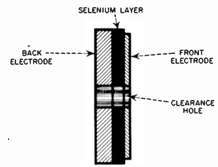
There are three types of dry-disc rectifiers in present general use; (1) copper oxide, (2) magnesium-copper sulphide, and (3) selenium.

Copper-Oxide Rectifier. The copper-oxide rectifier utilizes the asymmetrical conductivity characteristic of a low-valence oxide film formed on copper plates or discs. The conductivity of the cone-shaped crystals of this film is approximately 1000 times higher when the current flows from the oxide to the copper than when it flows in the reverse direction. The oxide rectifier, like other dry-disc types, thus is not a true valve but rather a very nearly unilateral device with resistance many times higher in the back than in the forward direction.

A rectifier element consists in effect of a cuprous-oxide disc and a metallic copper disc in contact, and means for making efficient electrical connection with the two. In order to achieve good molecular contact between the copper and oxide discs, an oxide film is formed directly upon the copper disc or plate. Thus, a single copper disc provides in one body both metallic and oxide members in intimate contact. Direct circuit connection may be made to copper "back plate" by connector tabs in the rectifier assembly, and the exposed oxide face may be connected to the external circuit through a disc of soft metal or metal foil ("face electrode") placed so as to be in contact with a maximum of oxide area. Copper-oxide rectifier units are shown in Figures 2 and 5.

In a typical manufactured copper-oxide rectifier element, a thin layer of graphite is spread evenly upon the oxide face, to prevent counter rectification at the interface of the film and the face electrode, and upon this layer is placed a disc or plate of sheet lead under pressure. High-pressure clamping is always employed in the manufacture of cuprous-oxide rectifiers unless the "collecting electrodes" of the rectifier elements have been sprayed or plated upon the oxide members to make contact pressure unnecessary.

While single rectifier elements might be employed in half-wave or full-wave circuits, a number of such elements



SINGLE ELEMENT OF SELENIUM RECTIFIER
Figure 4

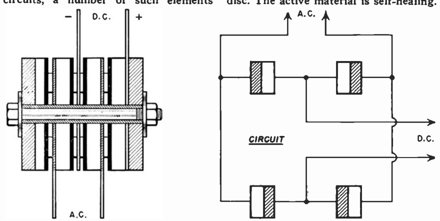
are generally assembled into one rectifier *unit*, being connected in a full-wave bridge circuit and clamped tightly together.

The copper-oxide rectifier has high thermal capacity, high efficiency, low operating cost, and it possesses indefinitely long life. On the other hand; it is larger in size and heavier in weight than other dry-disc types, its initial cost is higher, and its voltage regulation poorer under identical operating conditions.

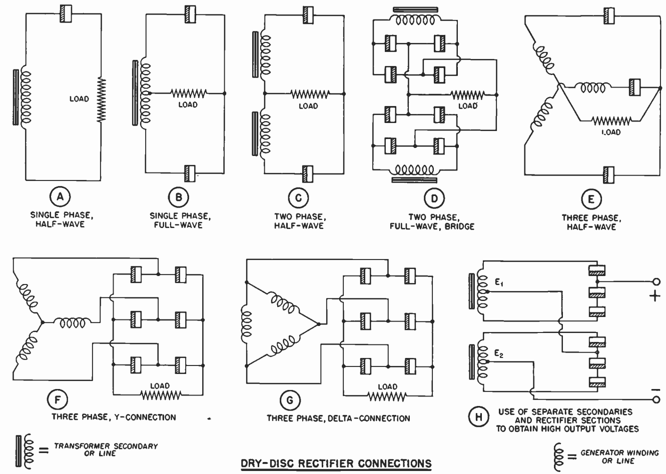
The ability of the copper-oxide rectifier to withstand short-term voltage overloads fits it particularly to applications where transients and other circuit phenomena introduce momentary overloads, or where intermittent voltage overloads are purposely applied.

Magnesium-Copper Sulphide Rectifier. This type of dry-disc rectifier (see Figure 3) is assembled from alternate discs or plates of magnesium and copper sulphide, together with appropriate spacer washers and assembly nuts to insure mechanical rigidity and good electrical contact. The discs are of the washer type and are stacked on an insulated bolt or threaded stud and clamped under high pressure.

This unit offers highest conductivity when the copper-sulphide disc is positive with respect to the magnesium disc. The active material is self-healing.



TYPICAL ASSEMBLY OF COMPLETE DRY-DISC RECTIFIER UNIT
Figure 5



DRY-DISC RECTIFIER CONNECTIONS
Figure 6

The magnesium-copper sulphide rectifier is small in size, has lower initial cost than the other dry-disc types, and is light in weight. It may be operated safely at a maximum temperature of 85°C. (185°F.) with convection cooling, or up to 130°C. (266°F.) with forced ventilation, and it possesses good voltage regulation. However, the efficiency of this type is relatively low, compared to dry-disc rectifiers of other types, and its life is limited. It is most satisfactory for intermittent duty in low-voltage applications. By applying it to intermittent service, the limited life of the magnesium-copper sulphide rectifier consequently may be prolonged. The number of magnesium-copper sulphide rectifier elements that may be operated in series is definitely limited.

A representative magnesium-copper sulphide rectifier unit operating into a resistance load exhibits 40% efficiency at full rated load in a single-phase circuit, and approximately 60% efficiency in a three-phase circuit. The efficiency drops at 100-percent current overload to approximately 37% for the single-phase unit and approximately 58% for the three-phase unit.

Selenium Rectifier. The selenium rectifier, widely used for a number of years in Europe prior to its introduction into this country, is assembled from plated-iron, aluminum, or steel discs or plates which are first coated with selenium, properly processed, and then sprayed with a single metal or alloy. The first plate constitutes the back electrode, while the sprayed-on plate becomes the face electrode.

Each such sandwich-type assembly (see Figure 4) forms a complete rectifier element in itself and thereby removes the necessity for high-pressure clamping of a stacked rectifier unit. The completeness of each element likewise enables increased disc spacing for easy ventilation.

In the selenium rectifier element, conductivity is highest when current flows from the iron, steel, or aluminum back plate into the selenium. The photoelectric effects, so well-known in connection with selenium, are eliminated or made inconsequential by the element structure and processing.

The selenium rectifier is smaller in size and lighter in weight for a given power-handling ability than are other dry-disc types. Its allowable operating temperature is higher than that of the copper-oxide rectifier, although the efficiency of the two types is very nearly the same.

The selenium rectifier may be subjected to brief current overloads without permanently injuring its elements. And, although this type unit will not handle voltage overloads safely, this inability occasions little difficulty since the voltage rating per element for the selenium rectifier is several times higher than that of the copper-oxide type. Unlimited life has been indicated by protracted life tests conducted by the manufacturers of selenium rectifiers.

Typical selenium rectifier characteristics under normal rated operating conditions are (1) Efficiency: 65% for single-phase, 85% for three-phase operation. (2) Stability: forward resistance rise is approximately 5% to 10% during an aging cycle consisting of the first ten thousand hours of normal operation, after which no further appreciable change takes place. (3) Power Factor: approaches unity. (4) Voltage regulation at normal ratings and temperature, with resistance load: 10% to 15% for single phase, 8% to 10% for three-phase operation. (5) Maximum plate temperature must not exceed 75°C. (167°F.)