

## THE COPPER-SULFIDE RECTIFIER AS A SOURCE OF POWER FOR THE PROJECTION ARC\*

C. A. KOTTERMAN\*\*

A rectifier may be defined as a device for converting alternating current into unidirectional current by mechanical, chemical, or electrical means.

Probably the most common mechanical rectifier is the motor-generator set. Another familiar type is the rotary converter. All rotating mechanical rectifiers are equivalent to converting the alternator source to a direct-current generator. Another mechanical rectifier that has wide application in the low-current field is the vibrator type, employing a tuned reed. This rectifier is used in about 90 per cent of all automobile radios, although in many cases, in this application it acts as an inverter instead of a converter. Another form of mechanical rectifier is the mercury-jet type, wherein a jet of mercury oscillates at appropriate frequencies between contacts performing the commutation. All mechanical rectifiers depend upon physical connection and the opening of an a-c. circuit at the correct times.

The chemical rectifier is referred to more to round out a résumé of rectifiers than for its commercial practicability, at least as a power-supply for the projection arc. The most common chemical rectifier is the electrolytic type, in which rectification depends upon a film formed on a metal electrode immersed in an electrolyte, with another electrode of inert material for contacting the electrolyte. A commercial rectifier of this type employs an electrode of tantalum, with lead as the other element, immersed in dilute sulfuric acid.

For the sake of simple classification, thermionic rectifiers such as vacuum-tubes, gas-filled tubes, and mercury arcs, fall into the electrical group. The vacuum-tube rectifier employing a hot filament is a familiar example, as it is found in practically every home radio set. A less familiar type, but of wide commercial usefulness, is the mercury-arc rectifier. One form consists of a hot cathode spot on a mercury pool to which the anode current flows. In another type a hot cathode operates in mercury vapor.

A rectifier falling in the electrical class and with which the balance of this paper will deal, is the magnesium-copper-sulfide dry disk or plate rectifier, first developed about fifteen years ago by S. Ruben. It consists of an electropositive conductor and an electronegative semiconductor in more intimate contact than physical juxtaposition and pressure can give. The electropositive element is magnesium; the electronegative element, copper sulfide. The rectifier is electronic in operation, the current flowing from the sulfide element to the magnesium element. In this, the conducting direction, the voltage drop across the junction is extremely low, remaining practically constant, regardless of load. In the non-conducting, or blocking direction, the resistance of the rectifying junction is quite high. Electric current flows when the magnesium is made negative with respect to the polarity of the sulfide side, and blocks the flow of electricity when made the positive side.

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The magnesium-copper-sulfide rectifier is known as the non-integral type, because the two components of the rectifier have a rectifying film formed between them by an electrical process. Because of the unique way in which the rectifying film is built up, it can stand overvoltage which, if it results in breakdown of the rectifying film, instantaneously heals itself without damaging the rectifier.

Any attempt to explain exactly how a contact rectifier operates usually becomes very much involved. It is beyond the scope of this article, therefore, to enter into

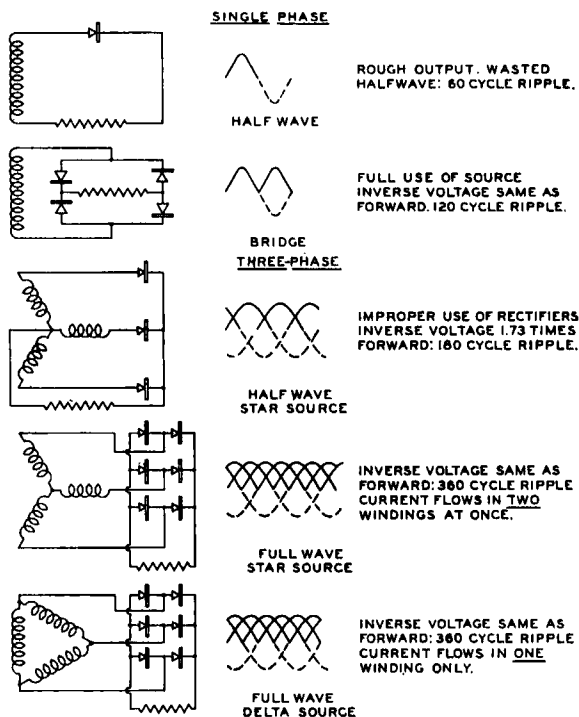


FIG. 1. Various circuit systems used with sulfide rectifiers.

a highly theoretical discussion of the physical principles underlying its operation. Suffice it to say that a rectifier that depends upon electronic action may be likened to a valve or gate: it opens the a-c. circuit 60 times per second when the half-cycle is of one sign, and closes the circuit when the half-cycle is of the opposite sign. Such rectifiers are all metallic, and have no moving parts, hot cathodes, glass parts, or other fragile constructional components.

The theater projection arc affords an ideal application for the copper sulfide rectifier. These arcs usually operate on currents varying from 50 to 65 amperes

at 35 volts. These values are particularly well suited to the copper sulfide rectifier, which is fundamentally a high-current, low-voltage type of rectifier.

In order to evaluate the magnesium-copper-sulfide rectifier in terms of useful power-supply devices for projection, it will be necessary at this point to describe

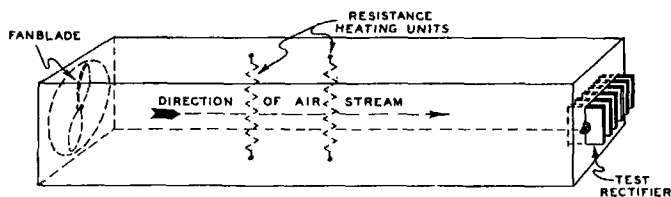


FIG. 2. Wind-tunnel test of rectifier ventilation.

several fundamental facts by which the performance of the sulfide rectifier is measured.

The first fact to establish is how much a-c. voltage will one rectifying junction block; in other words, how much a-c. voltage can be applied across the components of a junction without breaking down the insulating film between them? The magnesium-copper-sulfide rectifier will stand 3 to 3.75 volts rms. on load per junction. These are working voltages. Blocking peak voltages would be 1.4 times

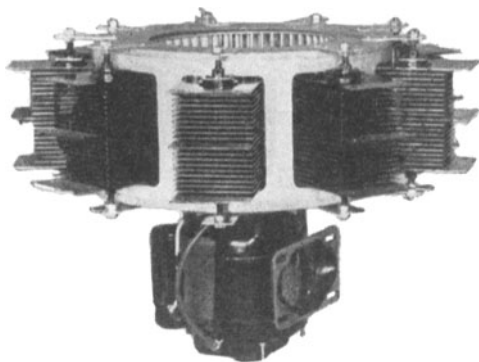


FIG. 3. Blower mounted inside drum structure, for forced ventilation.

these values. When these values are exceeded by 15 or 20 per cent there is the possibility of breakdown, resulting in rapid deterioration of the junction if the condition causing the breakdown persists. However, as previously stated, occasional overvoltage due to line surges, *etc.*, causing momentary breakdown in the rectifying film, will not affect the normal operation of the rectifier or its life.

Closely related to the permissible volts per junction is the ratio of d-c. output voltage to a-c. input voltage. For three-phase full-wave bridge operation it has

been found that the voltage ratio of the magnesium-copper-sulfide rectifier is about 85 per cent. In the case of the rectifier for projection, this means that 44 volts a-c. are impressed across a sufficient number of junctions in series to produce 35-36 volts d-c. at the arc. Another important factor is the current ratio; that is, the ratio of the direct-current output to the alternating-current input. The rectifier has approximately a 120 per cent current ratio for three-phase, full-wave circuit systems.

Having reviewed rectifiers in general and discussed the mechanism of the contact rectifier in particular, we can now consider details of design for a rectifier power supply for the projection arc. The essential features are:

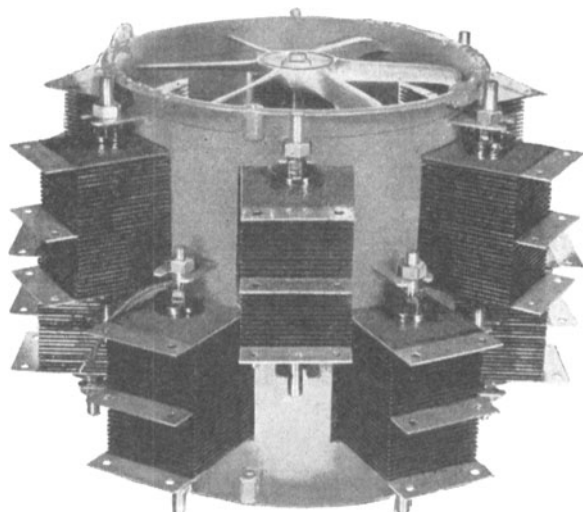


FIG. 4. Showing propeller-type fan for forced air cooling.

- (1) Most suitable type of a-c. circuit system.
- (2) Current-handling capacity of the sulfide rectifier as a function of life and operating temperature.
- (3) Cooling or ventilating methods.

As most projection arc rectifier applications call for d-c. voltages varying from 35 to 50 volts, it is necessary to employ a transformer to step down the 110- or 220-volts a-c. source to a suitable value to be used in the projection arc circuit.

Two basic circuits are employed with all contact rectifiers: the half-wave and full-wave bridge, single-phase, or polyphase. The full-wave bridge requires twice as many rectifier elements as the half-wave for the same voltage input. Fig. 1 shows various circuit systems.

The three-phase, full-wave bridge connection with the windings of the source delta-connected, has the lowest blocking peak voltage per element (it is the same as the forward voltage) and requires fewer junctions than some of the other poly-

phase systems. Because this is very desirable from an application viewpoint, this circuit is considered the best, giving, as well, a ripple six times the input frequency of 60 cycles. It may be mentioned that where filtering out the ripple is necessary, the higher its frequency the easier it is to filter.

All contact rectifiers are resistance devices; therefore, they generate heat when rectifying. The normal life expectancy of such a rectifier is based mainly on its operating temperature. The lower the operating temperature, the longer the life when other operating conditions are normal. Heat generated at the junction must, therefore, be removed faster than by simple convection cooling if the rectifiers are to handle large currents such as those associated with the carbon arc. The magnesium-copper-sulfide junction, designed for carbon arc use, having 1.7 sq.-in. of rectifying area with associated radiator plate of  $12\frac{1}{4}$  sq.-in. of area,

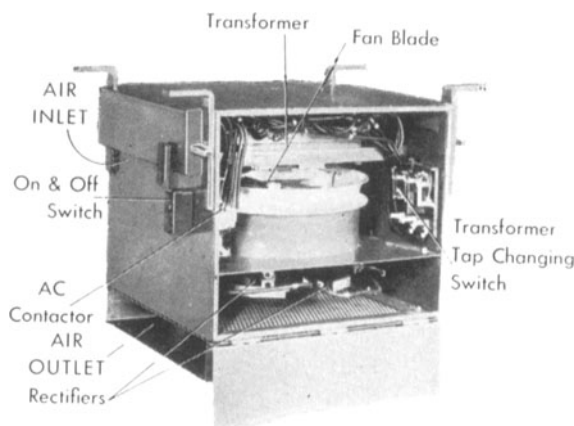


FIG. 5. Arrangement for ventilating rectifier for large power output.

will handle 38 d-c. amperes per sq.-in. safely and continuously. These current-densities are based on three-phase, full-wave operation.

One of the outstanding features of the copper sulfide rectifier is the ability to withstand unusually high operating temperatures. Fig. 7 shows a life-test curve on a copper sulfide rectifier purposely operated at temperatures considerably in excess of those encountered in the projection arc type of rectifier. Remembering that  $100^{\circ}\text{C}$  is the temperature of boiling water, it is readily understood that a rectifier that can withstand such a temperature continuously is truly remarkable. Any other type of contact rectifier would absolutely fail at such a temperature or at even much lower temperatures.

For low current-densities per rectifying junction, where the operating temperature will never exceed  $130^{\circ}\text{C}$ , the simplest method of cooling is convection cooling. Where the rectifier is required to handle large currents, as in the projection arc application, it is necessary to employ forced draft or so-called fan cooling.

A thorough study of rectifier ventilation has been made through the use of a wind-tunnel. Fig. 2 shows the set-up. The test rectifiers were mounted in a window opening at one end of a 10-ft. box. A fan, placed at the opposite end of the box, provided air velocities up to 5000 ft. per min. Electric resistance heaters were located inside the box midway between the ends, to raise the temperature of the air-stream to permit a study of the behavior of the rectifiers at elevated temperatures. The compiled data from the wind-tunnel tests makes it possible to design a transformer-rectifier combination to meet specific needs and to predict

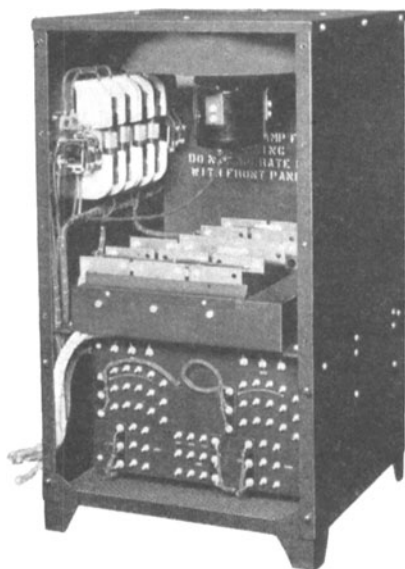


FIG. 6. Commercial form of sulfide rectifier with forced ventilation, for projection arc power supply.

within practical engineering limitations the operating temperature of a power rectifier for any given application.

To increase the current-handling capacity of the magnesium-copper-sulfide rectifier, fan or forced cooling was developed. This led to the study of accelerated air-flow through rectifiers and designs for compact assemblies. One form was to support the rectifier elements in the wall of a hollow drum structure, mounting a pressure-type centrifugal blower wheel inside the drum (Fig. 3). Air is drawn in through the opening in the squirrel-cage, then discharged from the blades through the rectifiers. This permits very compact construction, together with good cooling efficiency.

The rectifiers are placed symmetrically around the fan-wheel housing, which construction lends itself to very simplified wiring of the rectifiers. The whole

structure is usually supported on top of another housing in which the power transformer is placed. Air, discharged through the ventilating fins of the rectifiers, is first drawn up and around the coils of the transformer, thereby subjecting the transformer to forced cooling. In this way, smaller and lighter-weight transformers may be employed.

Where the rectifier cooling fins are close together, in order to make the assembly as compact as possible, high air velocity through the fins is desirable. Working closely with manufacturers of propeller-type fan blades, a satisfactory propeller blade was developed. The method of employing this type fan is shown in Fig. 4. A fractional horse-power motor is supported inside a drum cage. The motor shaft has a double extension, so that two fans, one right-hand and one left-hand, may be rotated simultaneously. Air is drawn in by both propellers, building up a pressure inside the drum, and is discharged out through the rectifiers which are mounted in openings in the drum. As a matter of passing interest, one power

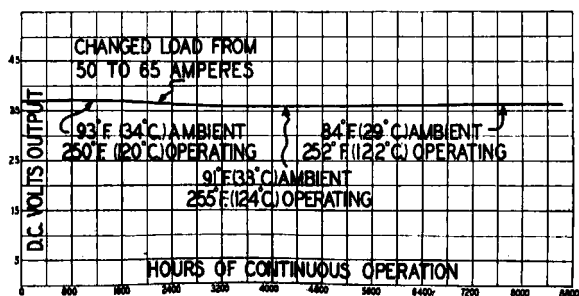


FIG. 7. Life-test of copper-sulfide rectifier designed for projection arc supply.

rectifier of this type (Fig. 4), employing rectifier junctions identical to those used in the rectifier for projection purposes, is only 16 inches in diameter and 12 inches high, weighs but 100 pounds including the ventilating system, and delivers 200 amperes at 40 to 50 volts. These figures, of course, do not include the transformer.

In the two cooling methods just described, the rectifiers are mounted around a drum or cage. A departure from this method is employed in a very recent development of fan-cooled rectifiers for large power outputs. In this equipment the rectifiers are mounted radially in a plane around the motor which drives a single large propeller developing an air pressure inside the housing and forcing the air out through the rectifiers (Fig. 5).

Where the rectifiers are operating at comparatively low current-densities, as in the case of the rectifier for the theater carbon arc, a simple adaptation of some of the foregoing cooling principles may be employed. Such an adaptation has been worked out excellently in the rectifier shown in Fig. 6. The transformer is placed at the bottom of a steel cabinet. The two banks of rectifiers (in the case of a twin arc power-supply) are supported in trays immediately above the transformer. The space around the trays is baffled to concentrate the air-flow through

the cooling fins of the rectifiers. A propeller-type fan blade of sufficient air capacity to maintain the operating temperature of the rectifiers considerably below their maximum safe operating temperature is driven by a motor mounted at the top of the cabinet. This simple cooling arrangement draws air in from the bottom, over and around the transformer, then through the rectifier cooling-fins, with discharge at the top, providing efficient cooling in a compact assembly.

Any discussion of the power-supply for the projection arc immediately raises the question of the relative merits of rotating equipment *vs.* rectifiers. Probably the most essential feature of a power-supply for the theater carbon arc is dependability regardless of the type of source. All other factors are of less importance. The theater operator or owner likes to feel that the equipment will operate satisfactorily and continuously and that the show will go on. Rotating equipment requires periodic servicing and maintenance. The magnesium-copper-sulfide rectifier, if properly ventilated and not subjected to abnormal operating conditions, performs satisfactorily over a long period of time without any attention whatsoever. Because of the large margin of reserve capacity in this rectifier designed for theater use, fan failure will not darken a theater. Instances have been reported from the field where the fan associated with a copper sulfide rectifier for theater use had failed and could not be replaced immediately, but the rectifier carried on for days until a new fan was installed. Such operating conditions are not to be encouraged, but they go to show that in the copper sulfide theater rectifier there is a power-supply available requiring practically no maintenance and one that will stand considerable punishment without failure.

Naturally, the theater owner is interested in the all-around performances of this power-supply and how long it will last. An extensive life-test has been run on the copper-sulfide rectifier employed in projection arc power-supplies. Fig. 7 shows the results of a test run on the machine shown in Fig. 6 extended to the equivalent of 10,000 hours of normal theater operation.

Improvement in the technic of processing the copper-sulfide rectifier and the experience gained during the past two years in building heavy-current rectifier power-supplies such as for electroplating, delivering 3000 d-c. amperes and upward, indicate that these improvements now being incorporated also in the projection arc rectifier will give the theater owner a more dependable source of power than ever before with an exceedingly long life.

#### DISCUSSION

MR. GESSIN: What is the average life of the copper-sulfide rectifier?

MR. KOTTERMAN: That depends upon a number of conditions: Operating temperature for one thing, variation in load, and the type of adaptation. For theater use, with the improved type of rectifier we are now building, we anticipate a useful life of five years.

MR. CRABTREE: What is the effect of high humidity?

MR. KOTTERMAN: None. The radiating fins and the rectifying elements are clamped together on a very heavy bolt, with spring washers at either end, to maintain constant pressure regardless of contraction and expansion during operation. The assembly is vacuum-impregnated with special varnish which prevents moisture from getting into the rectifier elements.

MR. CRABTREE: Magnesium is, of course, readily oxidized.

MR. KOTTERMAN: That is one reason why we are very careful to prevent moisture and air from getting to it.

MR. FINN: What is meant by "a useful life of five years"?

MR. KOTTERMAN: The life under operation conditions, depending upon the use of the equipment. It might be perfectly all right at the end of five years. We have rectifiers delivering much smaller outputs than the carbon-arc rectifier demands which have been in service ten years.

MR. FINN: The General Electric Co. ran some accelerated life tests on the copper-oxide type of rectifier equivalent to ten or eleven years of continuous running.

The phrase "useful life of five years" does not seem right. If General Electric ran them for ten years, exposed to all sorts of weather conditions, I do not see why this particular rectifier should be limited to a useful life of five years, provided the safety factor remains constant. I know that some railroad rectifiers have been running ten years.

MR. KOTTERMAN: We have been making this heavy-current type of construction only about two years, and the only thing we could do was to have an accelerated life-test, which we think is equivalent to five years. We stopped it at the end of that period in order to study the rectifying junctions. We have started another life-test that we may run an equivalent of ten years.

MR. FINN: We are not dealing with high amperages, only 50 or 60 amperes.

MR. KOTTERMAN: I think that is a rather high current. It means that the copper-sulfide rectifier is operating at a current-density of 38 amperes per square-inch.

I might qualify the term "useful life." One buys an automobile and expects a useful operating life of three years. It may continue to operate after that, but might not be quite as useful as it was during the first three years. Conceivably this rectifier may still operate at the end of five years and still be useful; or the voltage output may fall off to the extent where it is no longer giving useful service for the projection arc.

DR. CARVER: What happens when the rectifier does go bad? Does it go bad suddenly, or does it give warning?

MR. KOTTERMAN: It gives warning. The output begins to fall off.

MR. ROBERTS: What is the voltage drop through the rectifier unit on an arc application? What is the efficiency of the unit?

MR. KOTTERMAN: The rectifying efficiency of this type of copper-sulfide rectifier is 50 to 55 per cent. Depending upon the circuit conditions, the overall efficiency of the transformer-rectifier combination would be lower than the rectifying efficiency alone.

MR. ROBERTS: What is the drop through the unit?

MR. KOTTERMAN: One-half volt per junction.

MR. CRABTREE: What is that in comparison with the copper-oxide rectifier?

MR. ELDERKIN: The copper-oxide rectifier gradually ages. The output drops from the time it is new until you can not use it any longer. The resistance increases steadily; sometimes it will be so high as to cause overheating. This rectifier does not do that. It does not age. The efficiency is the same throughout a longer period of life. The copper-oxide rectifier will show a little higher effi-

ciency at the start, and lower efficiency when it is older. The average efficiency over a given length of time will about be the same for the two.

MR. CRABTREE: What is the ratio of input to output?

MR. ELDERKIN: That depends upon the circuit, the output, and the number of units used. In this particular application the efficiency will start at 60 to 65 per cent; with the copper-oxide it will drop to 40 or 45 per cent.

MR. CRABTREE: There must have been some outstanding advantage of this type of rectifier as compared with other types to spur your engineers to develop such ingenious equipment. What is this outstanding advantage?

MR. KOTTERMAN: In our opinion, the chief advantage of the copper-sulfide rectifier over the copper-oxide rectifier is its tremendous reserve capacity and the fact that it operates at an exceedingly high temperature without causing destruction of the rectifier elements. Also that we can build a rectifying device that will deliver the amperage associated with the carbon arc in a very small assembly.

One form of copper-sulfide rectifier measures 16 inches in diameter and 12 inches in height, weighs 100 pounds, and delivers 10 kw. of direct current. Of course, those figures do not include the transformer. I do not think there is any type of contact rectifier or other type of d-c. generator equipment that can deliver 10 kw. in so small a compass as that.

MR. THOMAS: What are the characteristics of this equipment on 25-cycle current, and what happens to the d-c. output in relation to an a-c. input voltage drop?

MR. KOTTERMAN: Laboratory measurements have shown very little difference between the overall efficiency at 25 cycles and at 60 cycles. Much larger transformers are required to operate on 25 cycles than on 60, but the results are practically identical.

MR. STRICKLER: We use from 50 to 100 of the tungar outfits for portable projection, travelling all over the country and encountering all kinds of conditions. The weight and size are very important. We have small arc lights using about 25 amperes. Would your rectifier be less in weight or in bulk than similar contact outfits? Single-phase supply is what we meet in almost all cases.

MR. KOTTERMAN: For single-phase operation I doubt that there would be much advantage as to size or weight over the tungar equipment. However, for polyphase operation there would be.

MR. STRICKLER: We are not so much interested in efficiency because we are in operation only for an hour or so at one time, but when a man has to set up a complete outfit in ten or fifteen minutes, equipment weighing 500 pounds in cases, put on a show in a room similar to this, tear down the equipment and put it into cases, and then put on another show in the afternoon of the same day several miles away, we have to consider size and weight. Our present units are stripped down to about 50 pounds per case. Would such capacity be possible with your outfit of similar size and weight?

MR. ELDERKIN: The rectifier units required, according to the voltage, would obviously be heavier than the equivalent number of tubes. Otherwise, the weight of the transformer, *etc.*, would be the same. The bulk would be greater.

MR. THOMAS: Does the reserve of the rectifier compensate for a-c. line fluctuations?

MR. KOTTERMAN: No, that is a matter of transformer design. With sufficient

reactance in the transformer you will maintain reasonably constant d-c. output under wide variations of a-c. voltage. A 10-volt variation in a 220-volt line might cause a variation of only 0.5 to 1 volt in d-c. output. Some very recent developments using highly reactive transformers are better than that.

MR. THOMAS: What happens when we strike the arc? Does the voltage jump, and then return to the proper value for operating the arc?

MR. KOTTERMAN: To answer your question completely and accurately it would be necessary to put an oscillograph on the output of the rectifier.

However, I have measured the current at the instant of striking the arc, and have found it to be of the order of 200 amperes. However, that only lasts but a fraction of a second, and immediately the carbons are separated the current and voltage return to normal.

MR. FIFERLIK: Is the rectifier likely to heat up if connected when the arc is not burning?

MR. KOTTERMAN: The rectifier for the projection arc or any other heavy-current application can withstand normal line-voltage input without suffering damage in any way. The leakage current of the copper-sulfide rectifier is much higher, of course, than that of the copper-oxide rectifier, but is not high enough to result in any dangerous temperature.

MR. DASH: With regard to "useful life," I should like to mention that there are motor-generator sets in operation in theater service that have had 20 years of useful service, and are still operating well. The presence of rotating parts does not limit the life of equipment if the equipment is well designed.

MR. CUTHBERT: Is there any disadvantage in breaking the d-c. circuit instead of breaking, as you normally do, the a-c. rectifier circuit?

MR. KOTTERMAN: It is more desirable, of course, to break the a-c. circuit because it is more sensitive to excess voltage than other types of contact rectifiers. But as I have said, we endeavor to engineer into each rectifier application the correct electrical characteristics so that if you do break the d-c. side or operate it under other circuit conditions, it will stand such operation without harmful results.

#### AUTOMATIC EMERGENCY SHUTTER SWITCH FOR THEATER FAN AND LIGHT CONTROL\*

E. R. MORIN\*\*

Everyone in the industry is impressed with the special fire hazards incident to the use of nitrocellulose film, and many precautions are taken for the abatement of fire and panic hazards in theaters. Herein is described a recent and very important development designed to control film fires in projection rooms by the installation of an automatic emergency control switch in addition to the usual

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\*\* Connecticut State Police, Hartford, Conn.