Oct. 20, 1942. J. SLEPIAN ET AL 2,299,184

LIGHTNING ARRESTER

Filed May 6, 1938

Fig. 1.

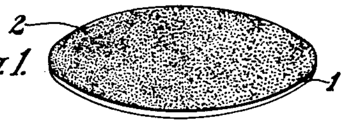


Fig. 2.

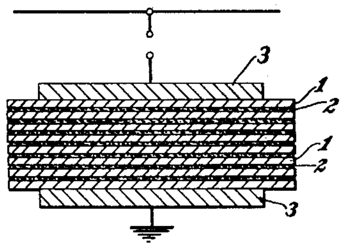
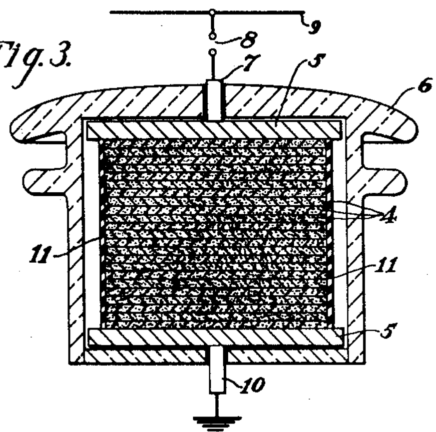


Fig. 3.



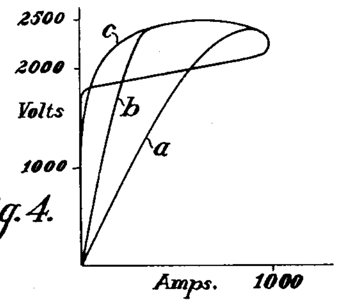


Fig. 4.

Fig. 5.

Fig. 6.

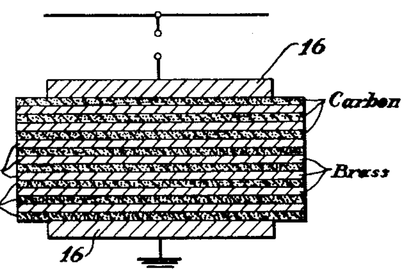


Fig. 7.

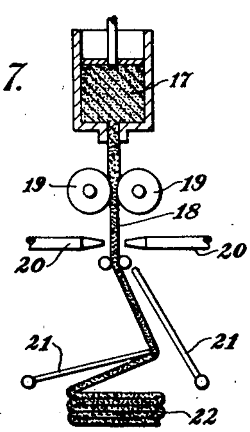


Fig. 8.

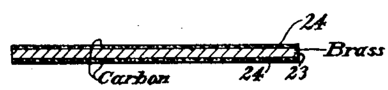


Fig. 9.

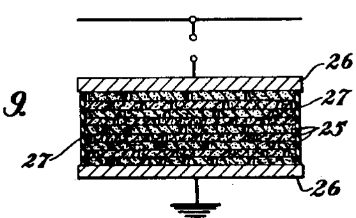


Fig. 10.

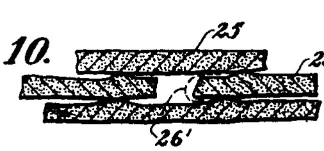
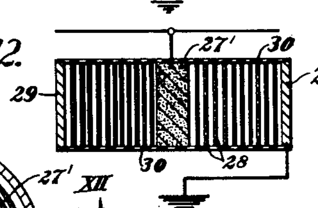


Fig. 12.



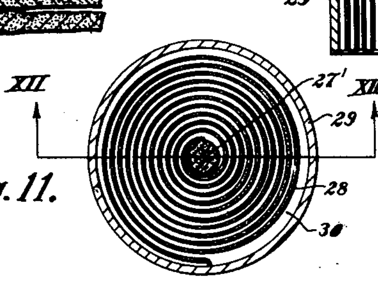


Fig. 11.

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Patented Oct. 20, 1942 2,299,184

UNITED STATES PATENT OFFICE

2,299,184

LIGHTNING ARRESTER

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Application May 6, 1938, Serial No. 206,342

8 Claims. (Cl. 201—68)

The present invention relates to lightning arresters and, more particularly, to an improved lightning arrester having a new principle of operation.

The principal object of the invention is to provide a lightning arrester operating on the arc discharge principle and having a very low ratio of breakdown voltage to cut-off voltage. Such an arrester consists essentially of a series of short arc discharge paths having low breakdown voltage connected between the transmission line or other electrical apparatus to be protected and ground. An arrester constructed in this manner has a very low ratio of crest voltage to cut-off voltage and very little, if any, increase of maximum voltage with increased rate of current rise. This arrester is also capable of handling much larger surge currents without damage than any of the standard types of lightning arresters now in use and is not damaged by very large power currents.

The operation of the new arrester is based on the fact that a thin layer of insulating, semiconducting, or finely divided conducting material placed between layers of conducting material has a low breakdown voltage which is very little larger than the minimum voltage necessary to maintain the discharge. For example, such layers may require from 15 to 20 volts to maintain a discharge with high surge current while, if the layer is thin enough, the breakdown voltage will be only from 25 to 40 volts. Thus a low voltage ratio can be obtained and a very satisfactory lightning arrester may be constructed by connecting a sufficient number of such discharge paths in series to give the desired voltage rating.

The invention will be more fully understood from the following detailed description of certain practical embodiments taken in connection with the accompanying drawing, in which:

Figure 1 is a perspective view of a disc suitable for use as an element of a lightning arrester,

Fig. 2 is a diagrammatic view of a lightning arrester,

Fig. 3 is a view partly in section of a preferred embodiment of the invention,

Fig. 4 is a graph showing the volt-ampere characteristics of the arrester of Fig. 3,

Fig. 5 is a transverse section of a lightning arrester disc,

Fig. 6 is a somewhat diagrammatic view of another form of the invention,

Fig. 7 shows diagrammatically one process of constructing a lightning arrester,

Fig. 8 is a sectional view of another form of lightning arrester disc,

Fig. 9 shows another embodiment of the invention,

Fig. 10 is a diagrammatic view on a larger scale of certain of the elements of Fig. 9,

Fig. 11 is a horizontal section of still another embodiment of the invention, and

Fig. 12 is a section on the line XII—XII of Fig. 11.

As stated above, it has been found that a thin layer of insulating or semi-conducting material placed between conducting surfaces has a very low breakdown voltage. A lightning arrester making use of this fact is shown in Figs. 1 and 2. This arrester comprises a series of thin layers of silicon carbide placed between metal surfaces, and is preferably built up of a series of thin discs 1, as shown in Fig. 1. These discs may be of brass or other suitable metal and have a thin coating of silicon carbide on one surface, as indicated at 2 in Fig. 1. This coating should be very thin and a layer of 300 mesh silicon carbide having a thickness approximately equal to the height of one grain of the silicon carbide forms a very satisfactory coating. The metal discs are preferably of the order of .005" in thickness. The lightning arrester is formed of a plurality of these discs arranged in a stack as shown in Fig. 2 and placed between metal electrodes 3.

Silicon-carbide layers such as these have a surge breakdown of approximately 35 volts and a cut-off voltage between 10 and 15 volts. A lightning arrester of any desired voltage rating is made simply by stacking the necessary number of these discs, thus providing a series of short arc discharge paths. Since the breakdown voltage between discs is not much greater than the arc voltage, the normal line voltage per disc will be a little less than the arc voltage, and for this reason the power current that tends to flow through the arrester after a lightning surge has been discharged is very small since the normal line voltage is insufficient to maintain the discharge. This fact makes the new arrester very well suited for use on direct current systems, as well as on alternating current systems, since the problem of interrupting the power follow current is much more difficult with direct current.

Such an arrester has a very large surge current capacity and a low ratio of breakdown voltage to cut-off voltage. Practically, however, this arrester is subject to the difficulty of producing a satisfactory silicon-carbide layer of the desired thickness and uniformity, and is also subject to concentration of the arc discharge which causes melting of the metal disc at the arc terminals, resulting in building up metal projections and short circuiting the silicon-carbide.

A more satisfactory type of arrester operating on the same principle is shown in a practical embodiment in Fig. 3. This arrester consists of a stack of thin carbon discs 4 arranged in series relation between electrodes 5 of brass or other suitable metal. As shown in Fig. 3, the arrester is preferably enclosed in a porcelain casing 6 and serially connected, by a lead 7, to a series gap 8 which performs the usual function of interrupting the power-follow current which flows through the leakage-resistance after the cutoff point of the arrester proper has been reached. The complete arrester is connected, at one end, to a transmission line conductor 9 or other apparatus to be protected and at its other end it is connected through a lead 10 to a suitable ground connection. This arrester has fairly high contact resistance between adjacent carbon discs and, therefore, provides a series of short arc discharge paths in the same manner as the arrester of Fig. 2. With the carbon disc arrester, however, little or no burning or erosion takes place at the arc terminals and the discharge appears to be uniformly distributed over the entire area of the disc so that no pits appear in its surface. Fig. 4 shows the volt-ampere surge characteristic of an arrester consisting of a stack of 100 carbon discs 1⅞" in diameter and $^1/_{64}$" in thickness, having a 275 gram electrode at the top. Curve *a* in this figure shows the first test, curve *b* the third and curve *c* is the characteristic obtained from the 10th and all succeeding tests. It will be seen from these curves that the contact resistance tends to increase with repeated operation and that a very desirable characteristic is finally obtained. The increase in contact resistance is apparently caused by deposits of finely divided carbon powder which has been vaporized by the high arc temperature and recondensed in a different form from the carbon of the disc.

The arrester shown in Fig. 3 uses discs having square edges. If the arc spreads near the edge of the disc, flashover may occur. This may be avoided by coating the edges of the discs with a thin coating of insulating paint or cement 11. Any suitable insulating compound may be used for this purpose and a mixture of Alundum and waterglass has been found to be a very satisfactory composition, since it acts as insulation and also tends to hold the discs in their proper position. As another means of preventing flashover, the disc 12 shown in Fig. 5, may be used. This disc has bevelled or tapered edges 13 so that the distance between adjacent discs is increased at the edge and the possibility of flashover is practically eliminated.

Reference has been made to the increased contact resistance resulting from repeated operation of the arrester. In some cases it may be desirable to increase this contact resistance in order to decrease the leakage current of the arrester and to make the contact resistance less sensitive to the pressure on the stack of discs. This will somewhat increase the breakdown voltage but it can still be kept low enough to give a very satisfactory voltage ratio. The contact resistance may be increased by coating one side of each disc with powdered carbon similar to that formed by the arc as described above. This may be done by mixing the finely divided carbon with liquid, spreading the mixture on the disc and then evaporating the liquid. Such a coating may also be formed by heating the disc or simply by dusting loose carbon powder on its surface. Coatings of carbon mixed with an organic liquid, such as shellac or varnish, may also be used to increase the contact resistance and with such coatings the resistance can be controlled by firing the disc at a temperature high enough to char the organic material. The higher the firing temperature is made, the lower the resistivity of the organic material will become. Insulating or semi-conducting coatings of other materials may also be used to increase or control the contact resistance between adjacent carbon discs. For example, a refractory powder, such as silicon carbide or Alundum, can be applied to the disc, either in dry form or in a liquid suspension. Other insulating materials such as silica, flint, and quartz may be used in powder form in this manner. Waterglass diluted to the proper thickness has been found satisfactory for this purpose, and shellac and organic paints and varnishes may also be used. Such organic coatings have the advantage that their resistance can be controlled by heating the disc with its coating. Mechanical separation of the carbon discs may also be used to increase the leakage resistance between the discs and spacers of thin paper have been found satisfactory for this purpose. Such spacers may be cut out of paper having a thickness of 0.3 to 0.5 mil and placed between the discs. In general, it may be said that any suitable coating of insulating or semi-conducting material may be applied to one or both surfaces of the carbon discs to control the contact resistance between them and in this way to get the desired characteristics of high leakage resistance without seriously increasing the breakdown voltage.

Fig. 6 shows diagrammatically an alternative construction of this type of lightning arrester in which metal discs 14 are alternated with carbon discs 15 between the brass electrodes 16. This arrester functions in the same manner as the carbon disc arrester and similar insulating coatings may be used between adjacent discs as described above. This arrangement has the advantage of more rapid dissipation of heat because of the better heat conductivity of the metal discs, thus increasing the ability of the arrester to handle high surge currents. It has been found that when metal discs are alternated with carbon in this manner, the arc does not concentrate in one spot on the metal disc but tends to travel around over the surface of the metal, so that there is no objectionable burning at the arc terminal.

The carbon discs used in the lightning arresters described above may be formed in a number of different ways. For example, powdered graphite may be molded by itself or may be mixed with any of a number of materials including thermoplastic powders such as "Bakelite"; molding powders such as clay, boric acid or talc; fibrous materials such as asbestos; or metal powders such as copper, zinc, iron or nickel. The mixtures formed in this way are then molded into discs of the desired dimensions by any suitable molding machine and after molding, an insulating coating is applied to the discs, if desired, and the discs stacked and fired to the proper temperature to drive off excess volatile matter and to carbonize partially or completely the organic materials present. Instead of molding the discs any of the graphite mixtures mentioned above may be extruded or rolled into thin sheets and the discs punched out with a die after which they are insulated, assembled and fired as described above.

Another method of construction is shown diagrammatically in Fig. 7, in which the graphite mixture 17 is extruded in a thin sheet 18 which passes between heated rolls 19 and then between a pair of nozzles 20 which spray an insulating coating on the strip. Lever arms 21, which may be oscillated by any suitable mechanism, fold the strip into layers as indicated at 22 and when a sufficient number of layers has been formed, the strip may be cut and the folded portion placed under pressure and fired. The edges are then ground off to give a circular shape, thus forming a cylindrical stack of insulated discs. This method of manufacture has the advantage of insuring uniformly spaced insulating layers and, therefore, provides greater uniformity of electrical breakdown between the discs. It should also be understood that instead of using an extruded mixture, as described, paper or cloth, either plain or impregnated may be used and carbonized in the firing operation. Thus the discs may consist either of substantially pure carbon or they may consist of mixtures of carbon with other materials, either conducting or non-conducting, and the term "carbon" is used in the specification and claims to include either the pure material or a mixture of carbon with a suitable binder to give a carbonaceous material having relatively low resistivity.

Fig. 8 shows another form of disc which may be used as a lightning arrester element. This element is composed of a thin metal disc 23, with a coating of carbon 24 on both sides. The carbon layer may be applied to the metal disc by sputtering in an electrical discharge, by spraying or painting a liquid mixture of carbon, by carbonization of layers of organic materials by means of heat or other suitable means. It is essential that a good contact between the carbon layer and the metal disc be made. Suitable materials for the disc are copper, iron or nickel. With this type of disc the metal serves as a mechanical support for the carbon and also as an electrical connection between the two layers. These discs may be made thinner than the carbon discs, thus reducing the overall height of the arrester. For example, the metal disc may be .006'' thick while the two coatings may each be .002''. The thinnest carbon discs that it is practical to use are about .018'' thick and hence a considerable reduction in height may be obtained by the use of the carbon coated metal disc.

Another embodiment of the invention is shown in Fig. 9 and consists essentially of a large number of small, thin, irregular shaped pieces of carbon 25 having flat parallel surfaces. These pieces are all of uniform thickness and are arranged in a plurality of layers between brass or other metal electrodes 26 and provided with an edge insulating coating 27. The carbon pieces may be uninsulated or they may have an insulating coating as described above upon one or both of their flat surfaces. The carbon pieces may be assembled loose in a suitable container or, if desired, they may be molded into a cylindrical block by means of a suitable binder. This arrester can be made of much less height for a given rating than the carbon disc arrester previously described, although its method of operation is the same. An enlarged view of several of the carbon pieces 25 is shown in Fig. 10, and it will be seen that the effect of their arrangement is to increase the flashover path between adjacent layers, indicated at 26', without increasing the overall height of the arrester.

Still another embodiment of the invention is shown in Figs. 11 and 12. The arrester shown in these figures comprises a central electrode 27', which may be of carbon, surrounded by a multilayer spiral coil of thin carbon 28 and having an outer cylindrical electrode 29 of carbon or brass. Edge insulation 30 is provided to prevent flashover. This arrester can be easily produced by coiling a strip of paper or cloth, either plain or insulated, on one or both sides, around the central electrode and then carbonizing the cloth or paper by firing. It will be apparent that the operation of this arrester is the same as those described above, since it provides a plurality of layers of conducting material having high contact resistance between them or separated by thin layers of insulating material.

It should now be apparent that the basic principle of the new lightning arrester may be embodied in a variety of different forms but that each of these forms consists essentially of a series of short arc discharge paths comprising a thin layer of insulating or semi-conducting material placed between conducting layers or that it may take the form simply of a series of conducting layers having high contact resistance between them. When a high voltage is applied to an arrester of this type, each of the arc paths in series breaks down so that the surge current is carried through the arrester by a series of short arcs. The initiation of the arc discharge may very probably be explained in the following way, although other explanations may be possible. The surface of the carbon discs, when viewed under a microscope, is not perfectly smooth but exhibits a few high spots which may be of the same order of magnitude as the distance between adjacent discs. Such points are relatively few but they have a finite resistance depending upon the area of contact with the adjacent disc and the resistivity of the material. The current concentrates in these points of contact and produces a high enough temperature to vaporize the carbon. This very quickly starts an arc discharge at this point and it is probable that several such discharges will start simultaneously. The heating at the arc terminals vaporizes the carbon without melting it and, under these conditions, the cathode arc terminal apparently travels very rapidly over the entire disc surface or many parallel discharges may appear extending over the surface. The vaporized carbon formed by the discharge recondenses in an amorphous form on the disc surface and may bridge the space between the discs, but when this occurs, the finely divided carbon particles formed in this manner have a high resistance because of their very small dimensions and loose arrangement. Other effects probably also contribute to the operation of initiating discharge, such as electron emission at the cathode because of the high field, and distortion of the dielectric field between the carbon discs by the insulating layer.

It has been found by tests that a lightning arrester built up of carbon discs and operating in the manner described above has many desirable characteristics. Ratios of crest voltage to cutoff coltage have been obtained as low as 1.3 to 2.0 and it has been found that this arrester will handle a much higher surge current without damage than any of the standard types of lightning arresters now in use. Thus, an arrester built up of 20 carbon discs stacked under light pressure was tested twice at 65,000 amperes crest surge current and four times at 110,000 amperes. The discs were not affected by this test and the temperature rise was only between 50° and 80° C. Other tests have shown that this arrester has very little, if any, increase in its maximum voltage with increased rate of current rise, and it has also been found that it will satisfactorily handle very large power currents without damage. This latter characteristic is of great importance in many applications where large power follow currents may flow through the arrester for a half cycle. Previously used types of lightning arresters have been found unsatisfactory for such service where these currents are very large. The carbon disc arrester, however, has been tested with 60 cycle power currents as high as 3,000 amperes without damage to the arrester.

It will be seen, therefore, that a lightning arrester having an entirely new principle of operation has been provided and that this arrester has very desirable characteristics. Certain specific embodiments of the invention have been illustrated and described, but it is to be understood that the invention is not limited to the particular embodiments shown herein but, in its broadest aspects, it includes all equivalent modifications and embodiments which come within the scope of the appended claims.

We claim as our invention:

1. A lightning arrester comprising a plurality of discs arranged in a stack, said disks being of metal with a thin coating of carbon on each side thereof and adjacent discs having high contact resistance between them.

2. A lightning arrester comprising a plurality of discs arranged in a stack, said discs being of metal with a thin coating of carbon on each side thereof and adjacent discs being separated by a thin layer of insulating material.

3. A lightning arrester comprising a pair of electrodes and a plurality of small irregular pieces of carbon arranged in closely spaced layers between the electrodes with their flat surfaces parallel.

4. A lightning arrester comprising a pair of electrodes and a plurality of small irregular pieces of carbon arranged in closely spaced layers between the electrodes with their flat surfaces parallel, said pieces of carbon having a thin, insulating coating on at least one side thereof.

5. A lightning arrester comprising a pair of electrodes and a plurality of small, flat pieces of carbon of uniform thickness arranged in closely spaced layers between the electrodes with their flat surfaces parallel.

6. A lightning arrester comprising a pair of electrodes and a plurality of small, flat pieces of carbon of uniform thickness arranged in closely spaced layers between the electrodes with their flat surfaces parallel, said pieces of carbon having a thin insulating coating on at least one of their flat surfaces.

7. An excess-voltage protective device for the protection of an electric circuit against excess voltages, said device including a discharge element comprising a plurality of layers of conducting material disposed in series relation, and means for holding said layers under substantially constant normal contact pressure, said layers being substantially in contact with each other and having high-resistance contacts such that arc discharges occur between adjacent layers at a breakdown voltage less than 40 volts per layer, the resistance of said layers and high-resistance contacts being such that the discharge element is capable of carrying only a very small leakage current under the normal voltage of said protected circuit, and the number of layers being such that the normal voltage of said circuit per layer is less than the minimum voltage required to maintain an arc discharge between adjacent layers.

8. An excess-voltage protective device for the protection of an electric circuit against excess voltages, said device including a discharge element comprising a plurality of carbon discs disposed in a stack, and means for holding said stack of discs under substantially constant normal contact pressure, said discs being substantially in contact with each other and having high-resistance contacts such that arc discharges occur between adjacent discs at a breakdown voltage less than 40 volts per disc, the resistance of said stack of discs being such that the discharge element is capable of carrying only a very small leakage current under the normal voltage of said protected circuit, and the number of discs being such that the normal voltage of said circuit per disc is less than the minimum voltage required to maintain an arc discharge between adjacent discs.

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