United States Patent

[11] 3,582,985

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[21] Appl. No. **798,718**
[22] Filed **Feb. 12, 1969**
[45] Patented **June 1, 1971**
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[54] **METHOD OF IMPROVING STRIP PAPER FOR ELECTRICAL INSULATION**
6 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **219/384,** 162/192, 324/54
[51] **Int. Cl.** **H05b 7/18**
[50] **Field of Search** 219/383–4, 162/138, 198, 253, 192; 317/260; 117/71, 102, 200; 29/25, 42; 324/54; 156/64

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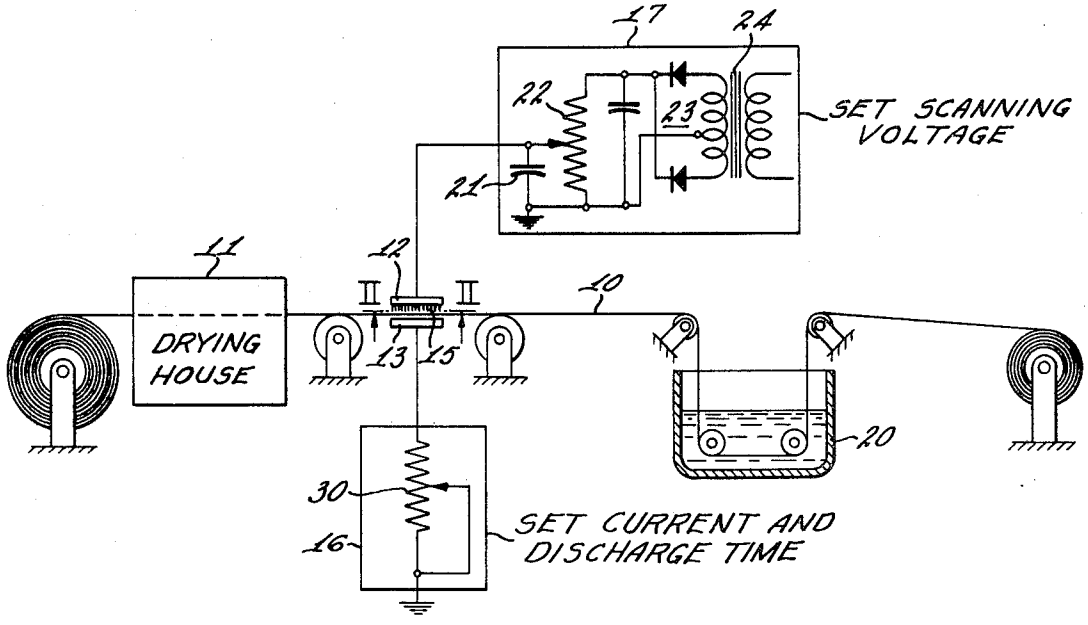
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ABSTRACT: The dielectric reliability of sheet electrical insulating is improved by removing conductive impurities of a selected size smaller than the thickness of the sheet and forming minute clean perforations in the sheet where the particles were removed. The sheet is scanned between opposing electrodes having a preselected potential applied therebetween to detect conductive particles of a desired size smaller than the sheet thickness, and sufficient current is discharged between the electrodes and through each particle for sufficient interval of time to remove the conductive particle and form a clean perforation without charring or tracking of the insulation.



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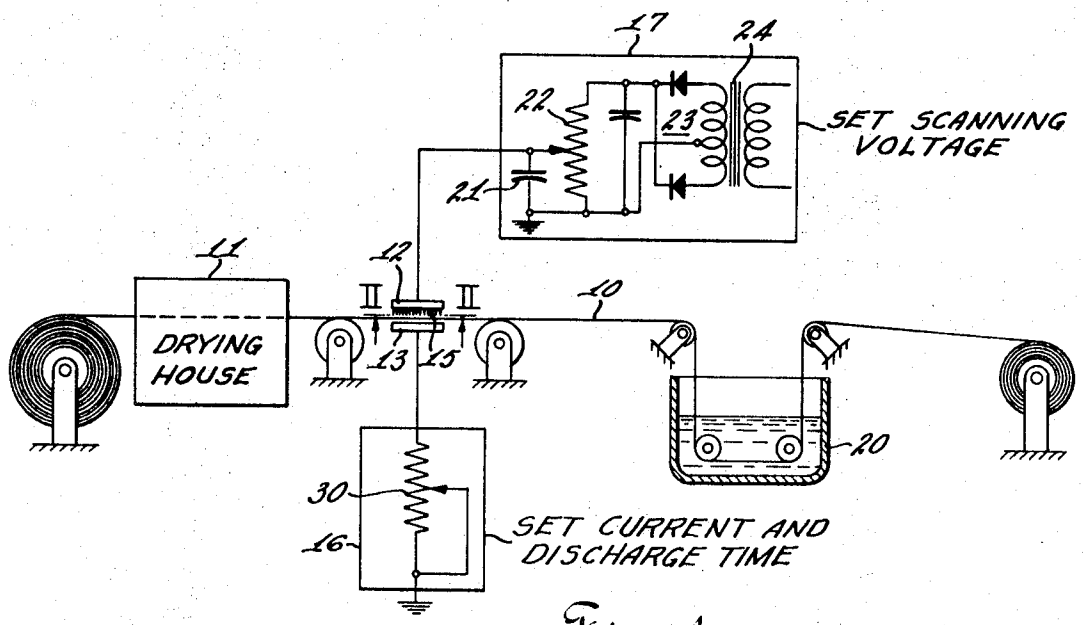


Fig. 1

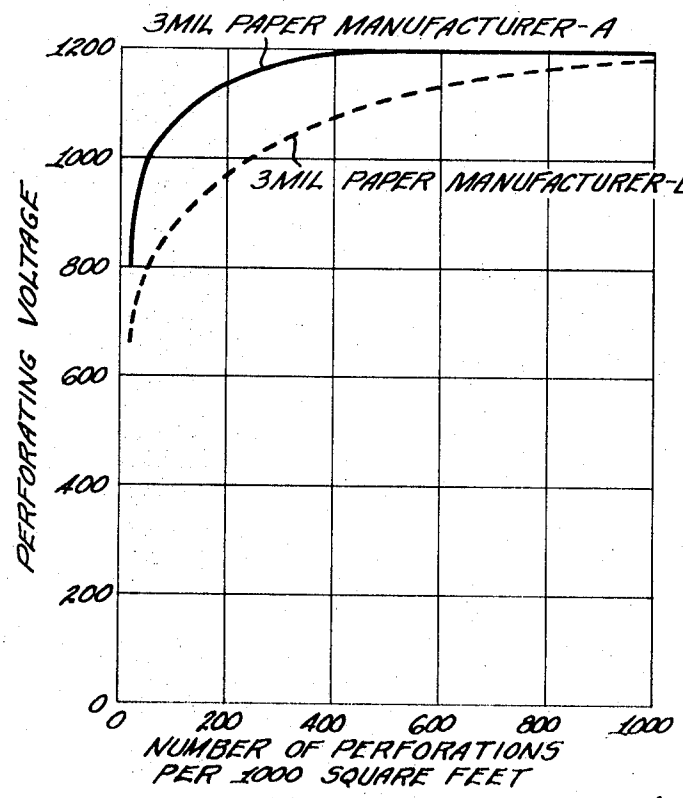


Fig. 3

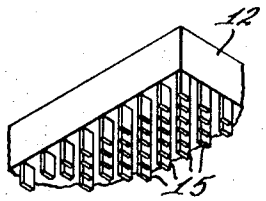


Fig. 2

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METHOD OF IMPROVING STRIP PAPER FOR ELECTRICAL INSULATION

This application is a continuation-in-part of my copending application Ser. No. 489,687 filed Sept. 23, 1965, now abandoned.

This invention relates generally to insulation paper for use in electrical apparatus. More specifically this invention relates to a method of increasing the dielectric reliability of electrical insulation paper.

It is a general practice in the manufacture of electrical equipment to use sheets of cellulose fibers obtained from wood, cotton, hemp and other selected plant life as electrical grade insulating paper. In spite of great care exercised by the manufacturer certain impurities appear in the finished paper stock. Some of these impurities are electrical conductors and when the paper is positioned between two conductors at sufficiently different voltage potentials the impurities conduct causing a breakdown of the insulation and a resulting failure of the electrical equipment.

In the past, paper of this type has been subjected to isolated voltage tests to determine its average minimum dielectric strength. When on occasion an extremely low value of breakdown voltage was found it was attributed to infrequently occurring weak spots, and the record was set aside as not being truly representative of the average dielectric strength of the paper. In general however a continuously rising voltage was applied until breakdown occurred, and the short circuit current that follows was interrupted by a circuit breaker, primarily to protect the test equipment. The edges of the breakdown spot are charred and if the rising voltage is again applied the second breakdown occurs at a reduced potential of 50 percent or less. Since this type of testing destroyed the insulation quality of the paper, the damaged sections had to be removed or multiple layers of insulation employed in the apparatus to be insulated.

It is an object of this invention to search out and remove certain impurities or dielectric weak spots in the insulation paper by employing a constant potential somewhat below the average minimum dielectric strength of a particular sheet of insulation. This is accomplished by subjecting the insulating paper to a dynamic energy impulse test prior to its use as insulation. As the paper strip is transported past a pair of scanning electrodes, the presence of conductive impurities and weak spots in the paper trigger a discharge circuit and a controlled amount of current is permitted to flow through the paper for a controlled amount of time. The disruptive current discharge is adjusted to the thickness of the paper and its mechanical strength to blow out the impurities to get a clean electrical perforation without burning or charring. The production of a carbonaceous material from burning and charring of the insulation paper causes contamination problems in electrical apparatus. It has been found that paper having perforated spots made in accordance with this invention will withstand a second application of scanning potential without further disturbance. Depending upon the weak spot variability of the paper the scanning potential used is made to closely approach the average dielectric strength desired for the paper. Hence this treatment removes the undesirable impurities without destroying the insulating properties of the paper.

Therefore it is the primary object of this invention to provide a new and improved electrical insulating paper having a high dielectric reliability. A more specific object is to provide such an electrical insulating paper characterized by the absence of conductive particles larger than a preselected diameter but smaller than the thickness of the paper.

Another object of this invention is to provide a new and improved method of treating paper having electric conducting impurities entrained therein. A more specific object is to provide such a method which removes the conducting impurities of a preselected diameter smaller than the thickness of the paper and without charring and tracking of the paper.

Other objects and advantages of this invention will be apparent from the following description when read in connection with the accompanying drawing in which:

FIG. 1 is a side view schematic diagram of the process and apparatus for treating insulation paper in accordance with this invention;

FIG. 2 is a partial perspective view taken along the line II–II of FIG. 1 specifically illustrating the area where the voltage is applied to the paper being treated, and

FIG. 3 illustrates the dielectric profile curves for papers from two different manufacturers.

Referring more particularly to the drawing, the invention is illustrated in a process which includes the steps of drying a sheet of insulation paper, subjecting the paper to the dynamic electrical impulse treatment, and then impregnating the treated paper with oil. Although this invention is being described in connection with the treatment of electrical insulating paper, it is intended that the treatment described will be applicable also to sheets of electrical insulation made of other dielectric materials as well as to sheets of paper for other uses.

After the paper **10** comes out of the enclosure **11** where it is dried, the paper passes between a pair of spaced directly confronting electrical conductors, or electrodes **12, 13** which contact opposite surfaces of the paper. The bottom conductor **13** over which the paper passes is a flat conductor bar. However the conductor bar **12** positioned above the paper has a plurality of fingerlike probes **15** which extend outward from the upper conductor bar to contact the paper. The purpose of the probes or fingerlike members is to provide individual voltage potentials to completely scan the entire surface of the paper passing between the conductors. Hence the conductors **12, 13** cover or extend over substantially the entire width of the paper as it is passing the conductors so that the entire surface area of the paper is exposed to the voltage potential. As the paper passes between the conductors any dielectric weak spots or electrical conducting impurities larger than a preselected size are located and a current pulses through these impurities which in effect blasts the conducting particles out of the paper.

The magnitude of the current pulse and its duration are controlled by discharge circuit elements **16, 17** to match the density and thickness of the paper and to produce clean perforations in the paper of a controlled size without charring and tracking of the paper. The electrical techniques to accomplish this control are well known to those versed to the art of impulse testing. The disruptive force of the blast caused by the current pulse removes the impurity leaving a pinhole sized perforation in the paper. These perforations are nearly identical to a large number of perforations that are normally present in paper stock or electrical sheet insulation as it is received from the mill. Hence they do not add significantly to the total open area in the paper. After the electrical impulse treatment the paper passes through a tank **20** where it is impregnated with oil or other liquid insulation. During this step in the process all the perforations in the sheet are filled with the liquid to form a solid wall of insulation. In some cases it may be desirable to fill the perforations with a solid material such as wax, plastic, or clay.

While the idea of applying a voltage such as an impulse test to the surface of insulation paper is not new, in the past it was done in highly limited circumstances and for different purposes than those to which this invention is directed. For example, after a voltage impulse test the voltage breakdown spot was sometimes removed from the paper. However in most cases this procedure was not practical for general use. It is also common in the electrical industry to employ multiple layers of sheet insulation. In this case whether or not the weak spots in the sheets were removed was immaterial because the high redundancy of many layers of insulation meant that the average dielectric strength of the sheet was not being exploited.

The use of a dynamic energy test such as described in this invention differs from the prior art impulse test in that the magnitude of voltage applied is intended to be "nondestructive" in the sense that it is not intended to test the paper to its ultimate strength and thereby possibly destroy portions of the

paper. Rather, the treatment is intended to remove certain impurities in the paper that are likely to break down during normal operation while not destroying the remainder of the paper.

While the removing of the impurities in the dielectric paper will naturally tend to upgrade the overall rating of the paper, the primary purpose of the treatment of this invention is not to increase the dielectric rating of the paper but rather to increase the dielectric reliability of the paper. In other words, the impurities that are being removed by the dynamic energy treatment are those that would cause a premature failure of the paper when it is being used at a predetermined voltage and/or temperature level in an application for which the paper is rated. Hence the purpose of the treatment is to provide an insulation paper that will have a longer life expectance than similar but untreated insulation paper when used in the same application.

It is well to point out that the treatment described herein has the effect of improving the appearance of the paper by removing the impurities which are frequently a different color than the paper per se. Hence this process is useful in treating papers that are used for purposes other than electrical insulation. An example of such a paper is cigarette paper in which a pure white appearance is desired. The voids formed by the dynamic energy treatment may be filled with pure white clay to further improve the appearance of the paper.

In operation a roll of paper **10** to be treated is placed on a spindle and threaded through the drying cubicle **11**, between the conductors **12, 13** and through a container **20** filled with insulating oil. As the paper **10** passes through the cubicle **11** substantially all the moisture is removed from the paper. Then as the paper is passing between the conductors **12, 13** a scanning potential is applied across the conductors of the paper being treated.

Any desired voltage potential may be set in control circuits **16** and **17** to match the density and thickness of the paper being treated, and it is usually set as just below the desired average dielectric strength of the paper. All conductive particles in paper insulation are not of the same size, and further not all conductive particles are detected by a given scanning voltage. Variation in scanning voltage changes the number and size of conductive impurities removed. The size of conductive particles to be detected and removed, and thus the degree of "cleanliness" of the paper, can be selectively varied by adjusting the scanning voltage from circuit element **17** applied across conductors **12** and **13**. FIG. **1** schematically illustrates that the voltage built up across a storage capacitor **21** having one side grounded and the other side connected to scanning electrode **12** can be adjusted by the slider of a potentiometer **22** to select the desired scanning voltage, and this figure also represents schematically that the direct current voltage applied across the winding of potentiometer **22** is generated by a full wave rectifier **23** energized from a transformer **24** having a secondary winding with the midtap grounded.

The optimum scanning voltage to be applied across electrode **12** and **13** to remove conductive particles of a given size is not a constant but rather is variable with many factors such as the paper manufacturer, type of paper, density, bursting strength and moisture content. The ability of papers of different structures, densities and thicknesses to withstand breakdown voltages can be statistically approximated if predetermined lengths of paper are scanned and the scanning voltage is raised in successive steps and such voltages are plotted against number of perforations (and thus number of conductive particles removed) for a given area of paper scanned. The curves plotting such scanning voltages versus number of perforations are termed "dielectric profiles" and reveal the dielectric strength of the paper and provide information regarding its dielectric reliability. FIG. **3** illustrates two such dielectric profiles for similar papers 3 mils thick from two different manufacturers plotting scanning voltage as ordinates versus the number of perforations per 1000 square feet scanned as abscissa. It will be noted that as the scanning voltage is raised in successive steps, the number of particles removed increases in such a rapidly accelerated manner that the number of perforations becomes asymptotic at a particular voltage. This asymptotic level of voltage establishes the maximum potential that the paper is capable of withstanding even if it were entirely free of conducting particles.

As shown in FIG. **3**, if 1000 volts is applied between scanning electrodes **12** and **13**, approximately 50 conductive particles per 1000 square feet scanned are removed from the paper of manufacturer A, while approximately 230 conductive particles per 1000 square feet scanned from the paper of manufacturer B. For practical purposes it can be considered that the portion of the dielectric profile curve below the knee is formed by the relatively infrequent presence of conducting particles, while the portion above the knee reveals the true dielectric strength of the "pure" paper. The scanning potential may be set in the range from 50 percent to 150 percent of the one minute dielectric strength in air of the paper being treated, and preferably it should be just below the desired average dielectric strength for the paper and thus just below the knee of the dielectric profile curve. Experience has shown that a voltage in excess of 300 volts/mil. of paper thickness is a generally satisfactory potential for most electrical insulation papers and also that low failure rates are obtained in coils manufactured with paper processed in accordance with the invention if the scanning voltage is adjusted so that approximately 50 conductive impurities are removed for each 1000 square feet of paper scanned.

The time of discharge and the magnitude of the current discharged between electrodes **12** and **13** (and thus through a conductive impurity in the paper being scanned) should be adjusted to produce a clean perforation in the paper which will subsequently provide the desired dielectric breakdown strength. A potentiometer **30** shown in circuit element **16** and connected between electrode **13** and ground permits adjustment of the magnitude of the discharge current and the time of discharge. If the perforating discharge current is too low, the metallic impurity may not be completely removed, the paper will be charred, and a burned path with a continuous track will be formed on the paper that materially reduces the dielectric strength of the paper. On the other hand, an excessively high discharge current is so disruptive that relatively large portions of the paper are blasted away leaving irregular holes whose edges are raised by blown-apart fibers but contain no visible conducting carbon. Preferably the discharge current and the discharge time are adjusted by potentiometer **30** so that clean perforations, i.e., minute holes with smooth burrless edges, are formed in the paper from which the metal particle has been completely removed without charring and tracking of the paper. The charge $Q=CE$ stored in capacitor **21**, and thus the magnitude of the discharge current and the RC time constant of capacitor **21** and potentiometer **30**, is a function of the scanning voltage E, but it is simple for the operator to find by visual inspection of the perforations a setting of potentiometer **30**, and thus a magnitude of discharge current and discharge time, which will completely remove the desired size of conductive impurity and provide clean perforations. Further, such setting is not critical for a broad range of parameters.

It is applicant's theory that a conductive particle is blasted out of the paper when it is confined between directly confronting electrodes **12** and **13** directly engaging opposite surfaces of the paper and a current of sufficient magnitude is discharged between the electrodes to evaporate the moisture in the paper and generate sufficient gaseous pressure to propel the conductive particle out of the paper in a manner analogous to the propulsion of a bullet out of the confined space within a cartridge when powder is exploded and gas is evolved within the cartridge. Enlarged photographs of the perforations in paper treated in accordance with the invention reveal the tracks along which the metal particles were propelled out of the paper and also reveal portions of the con-

ducting impurities remaining in the paper when the discharge current was too low.

The entire surface of the paper **10** is exposed to the voltage potential and the impurities in the paper forming dielectric weak spots are blasted out of the paper leaving minute pinholes in the paper. The paper **10** is then submerged in the oil in container **20**, and the paper becomes saturated with oil which also films over the pinholes in the paper. This leaves a paper that provides a solid wall of insulation.

Although but one embodiment of this invention has been illustrated and described, it will be apparent to those skilled in the art that various modifications and changes can be made therein without departing from the spirit of the invention or the scope of the appended claims.

I claim:

1. A method of treating a sheet of electrical paper insulation to remove conductive impurities from said sheet of a preselected diameter smaller than the thickness of said sheet comprising the steps of

passing said paper sheet containing said conductive impurities between a pair of directly confronting opposed conductive electrodes at least one of which has a plurality of probes spaced apart both longitudinally and transversely of said sheet so that said electrodes directly engage opposite surfaces of said sheet,

connecting an adjustable electrical circuit across said pair of electrodes and adjusting said circuit to apply a predetermined voltage of sufficient magnitude across said electrodes so that a discharge current is triggered by the presence between said electrodes of a conductive impurity in said sheet of said preselected diameter smaller than the thickness of said sheet, said predetermined voltage being in the range from 50 percent to 150 percent of the one minute dielectric strength in air of said sheet of paper insulation, adjusting said circuit independently of said voltage-adjusting step so that said discharge current is of sufficient magnitude and flows between said electrodes for a sufficient interval of time to remove said impurity and form a controlled perforation in said sheet without charring and tracking of said sheet, and impregnating said sheet with high dielectric strength oil to fill said perforations and form a solid wall of insulation.

2. A method in accordance with claim 1 wherein said discharge current is of sufficient magnitude to form at least 50 of said perforations in each 1000 square feet of paper passed between said conductive electrodes.

3. A method in accordance with claim 1 wherein said predetermined voltage is approximately 300 volts per mil. of paper thickness.

4. A method of treating electrical paper insulation sheet to remove conductive particles therein larger than a preselected diameter, which diameter is smaller than the thickness of said sheet, comprising the steps of

passing said paper insulation sheet between directly confronting opposed conductive electrodes directly engaging opposite sides of said sheet to scan the surface of said sheet, at least one of said electrodes having a plurality of probes spaced apart both longitudinally and transversely of said sheet,

connecting across said pair of electrodes an electrical circuit adjustable in both voltage and in the magnitude of current which will flow between said electrodes when a discharge is formed between said electrodes,

adjusting said circuit to apply across said electrodes a predetermined voltage slightly below the desired average dielectric strength of said sheet and of sufficient magnitude to detect a conductive particle in said sheet of said preselected diameter smaller than the thickness of said sheet as it passes between said electrodes and trigger a discharge between said electrodes,

adjusting said electrical circuit independently of said voltage-adjusting step so that said discharge current between said electrodes is of sufficient magnitude to remove said particle and form a clean perforation in said sheet without charring and tracking of said sheet, and impregnating said sheet with high dielectric strength liquid to fill said perforations and form a solid wall of insulation.

5. A method of treating a sheet of electrical insulation paper to remove conductive particles therein of a preselected diameter smaller than the thickness of said paper sheet, comprising the steps of

passing said paper sheet between a pair of directly confronting opposed conductive electrodes at least one of which has a plurality of probes spaced apart both longitudinally and transversely of said sheet so that said electrodes directly engage opposite surfaces of said sheet,

connecting an adjustable electrical circuit across said electrodes and adjusting said circuit to apply a predetermined voltage of sufficient magnitude across said electrodes to trigger a discharge current between said electrodes when a conductive particle in said sheet of said preselected diameter smaller than the thickness of said paper sheet appears between said electrodes,

adjusting, independently of said voltage-adjusting step, both the magnitude of discharge current from said electrical circuit across said electrodes and the time of said discharge so that a sufficient magnitude of current flows for sufficient time to remove from said sheet said conductive particle of said preselected diameter smaller than the thickness of said sheet and form a clean perforation of controlled size therein without charring and tracking of said paper sheet, and impregnating said sheet with high dielectric strength oil to fill said perforations and form a solid wall of insulation.

6. A method in accordance with claim 5 wherein said paper has a dielectric profile characteristic which plots scanning voltage across said electrodes versus the number of perforations per given area of said paper scanned between said electrode and which characteristic has a knee and becomes asymptotic with increase in scanning voltage and wherein said predetermined voltage across said electrodes is near or above said knee of said dielectric profile characteristic.