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PHOTOELECTROPHORETIC IMAGING METHOD INCLUDING CONTACTING THE IMAGING SUSPENSION WITH A LARGE SURFACE OF A FLEXIBLE ELECTRODE

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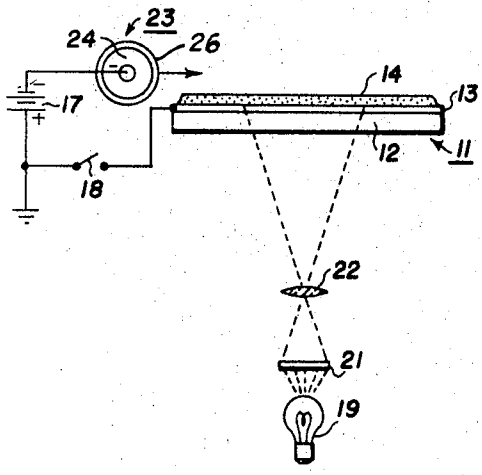


FIG. 1

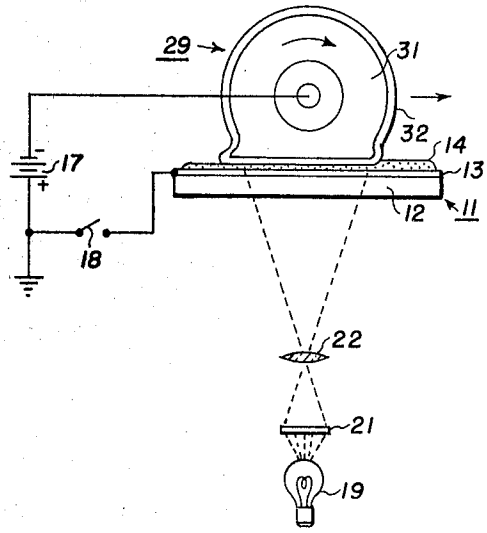


FIG. 2

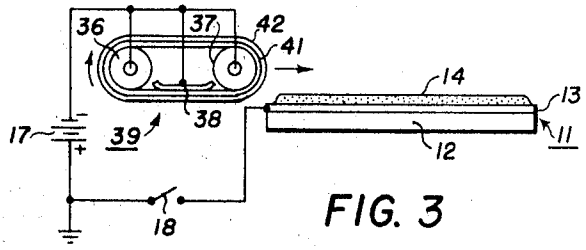


FIG. 3

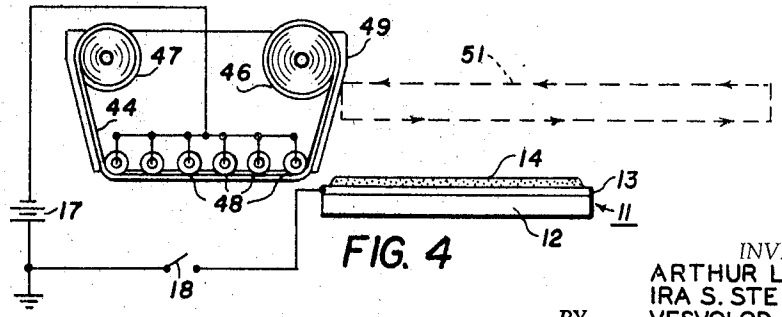


FIG. 4

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PHOTOELECTROPHORETIC IMAGING METHOD INCLUDING CONTACTING THE IMAGING SUSPENSION WITH A LARGE SURFACE OF A FLEXIBLE ELECTRODE

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U.S. Cl. 204—181 6 Claims

ABSTRACT OF THE DISCLOSURE

A method of photoelectrophoretic imaging is described wherein the imaging suspension is contacted by a large surface area of a flexible electrode. The electrode may be a compressible material, an endless belt, or an elongated web. The image produced may be either monochromatic or polychromatic.

This invention relates in general to imaging systems and, more specifically, to a photoelectrophoretic imaging system.

In photoelectrophoretic imaging colored particles are suspended in an insulating carrier liquid. This suspension is then placed between a pair of electrodes, subjected to to a potential difference and exposed to an image to be reproduced. Ordinarily in carrying out the process the imaging suspension is placed on a transparent electrically conductive plate in the form of a thin film, and exposure is made through the bottom of this plate while a second cylindrical electrode is rolled over the top of the suspension. The particles are believed to bear an initial charge when suspended in the liquid which causes them to be attracted to the transparent base electrode and to change polarity by exchanging charge with the base electrode upon exposure so that exposed particles migrate across to the roller electrode to form an image on the base electrode by particle subtraction. The system may be used to produce monochromatic images by using a single color of particle in the suspension or a number of differently colored particles in the suspension which all respond to the same wavelengths of light exposure. In polychromatic systems mixtures of two or more differently colored particles which are each sensitive only to light of a specific different wavelength or narrow range of wavelengths are used. Thus, for example, a full color image may be produced by using a mixture of cyan, magenta and yellow particles which respond to red, green and blue light, respectively. An extensive and detailed description of a photoelectrophoretic imaging technique as described above is found in copending applications Ser. Nos, 384,737, now U.S. Patent 3,384,565; 384,-681, abandoned in favor of application, Ser. No. 655,023, now U.S. Patent 3,384,566 and 384,680, abandoned in favor of application Ser. No. 518,041, now U.S. Patent 3,383,933, filed Jan. 23, 1964.

Although it has been found that good quality images can be produced especially when a relatively insulating "blocking electrode" surface is used on the roller, photoelectrophoretic imaging speed is relatively low frequently requiring light levels in excess of 100 foot candle seconds incident on the imaging plane. Such levels of illumination are quite difficult to attain with opaque originals so that the utility of the system tends to be limited.

Accordingly, it is an object of this invention to provide an improved photoelectrophoretic imaging method.

It is a further object of this invention to provide a novel and improved photoelectrophoretic apparatus.

A still further object of this invention is to provide a photoelectrophoretic imaging system with markedly higher imaging speed.

An additional object of this invention is to provide a photoelectrophoretic imaging method and apparatus using low levels of image illumination.

Another object of the invention is to provide a photoelectrophoretic imaging system capable of forming high quality images in both black and white or other single colors and in two or more colors including full natural color.

The above and still further objects of the invention are achieved, generally speaking, by initially rolling a large area of an electrode into contact with the particle suspension on the optically transparent base electrode in a photoelectrophoretic imaging system and then rolling it off. This type of movement is much like that on the tread of a tank and the electrode shall therefore be referred to as the "tracking electrode." This moving electrode is used in place of the rolling electrode in the system described supra and may take the form of an elongate web which is supplied from a roll and taken up by a second roll after it has contacted the suspension. The tracking electrode may also take any other suitable form. For example, it may take the form of an elongate endless belt entrained over two or more rollers so that the belt can be tracked over the suspension. In still further alternative embodiments the moving electrode may take the form of a very soft roller which is pressed against the transparent base electrode with the suspension thereon with sufficient pressure so as to deform the roller and provide a relatively large flat area of contact between the roller and the base electrode. Although both simple hard roller electrodes and planar non-moving electrodes have been tested in photoelectrophoretic imaging techniques, the large area rolling contact or "tracking" electrode of this invention seems to provide some type of surprising synergistic effect on the imaging system which is not clearly understood, since this type of electrode has been found to be capable of producing images at illumination levels below 2 foot candle seconds. Accordingly, exposure time may be drastically shortened by employing the imaging system of the present invention. In addition, it has been found that increases in the applied voltage between the electrodes of the system of this invention can be used to modulate system efficiency much more effectively than could be done in the prior atr systems.

In order that the invention will be more clearly understood, reference is now made to the accompanying drawings in which various embodiments of the invention are illustrated by way of example and in which FIGURE 1 is a side sectional view of one of the original photoelectrophoretic imaging systems;

FIG. 2 is a side sectional view of one embodiment of the photoelectrophoretic imaging system according to this invention;

FIG. 3 is a side sectional view of a second embodiment of the system of this invention; and,

FIG. 4 is a side sectional view of a third embodiment of the imaging system of this invention.

Referring now to FIGURE 1, there is seen a transparent electrode generally designated **11** which in this instance is made up of a layer of optically transparent glass **12** overcoated with a thin optically transparent layer **13** of tin oxide. This oxide coated glass is commercially available under the trade name NESA glass from Pittsburgh Plate Glass Company, Pittsburgh, Pennsylvania. This base electrode is referred to as the injecting electrode. Coated on the layer of electrode **11** is a thin layer of finely divided photosensitive particles dispersed in an insulating carrier liquid. This suspension may also contain sensitizers and/

or binders for the particles which are dissolved or suspended in the carrier liquid along with the particle. Adjacent electrode **11** is a roller electrode **23** which is connected to one side of a potential source **17** through a switch **18** with the opposite side of the potential source being connected to the tin oxide coating on electrode **11** so that when switch **18** is closed an electric field is applied across the liquid suspension as electrode **23** rolls across the surface of electrode **11** in the direction indicated by the arrow in the drawing. Electrode **23** is made up of a central core **24** which is preferably of fairly high electrical conductivity and is covered with a layer of blocking electrode material **26** which may, for example, be Baryta paper. Although a blocking electrode material such as **26** need not necessarily be used on the surface of electrode **23**, the use of such a layer is preferred because of the importantly improved results which it is capable of producing. A detailed description of these improved results and the types of materials which may be employed as this electrode coating material are described in detail in copending application No. 384,680 referred to supra. Extensive lists of materials for the particles and carrier liquid in suspension **14**, the injecting electrode etc. and for processing parameters such as the magnitude of potential to be applied and the like are also to be found in this patent application and the other two applications referred to supra, and all three of these applications are accordingly incorporated herein by reference. An image projector made up of light source **19**, a transparency **21** and a lens **22** is provided to expose suspension **14** to a light image of the original transparency **19** to be reproduced. In imaging the roller **23** is caused to roll across the top surface of electrode **11** with switch **18** closed during the period of exposure. This exposure causes exposed particles originally on electrode **11** to migrate through the liquid and adhere to the surface of the blocking electrode leaving behind a particle image on the injecting electrode surface which is a duplicate of the original transparency **19**. This image may then be fixed in place as, for example, by placing a lamination over its top surface or by virtue of a dissolved binder material in the carrier liquid such as a paraffin wax or other suitable binder that comes out of solution as the carrier liquid evaporates. In fact, the carrier liquid itself may be a molten paraffin wax or other suitable binder in a liquid state which is self-fixing upon cooling and return to the solid state. In the alternative, the particle image remaining on the electrode **11** may be transferred to another surface and fixed thereon, if desired. The system has ben found to be capable of producing either monochromatic or polychromatic images depending upon the color, sensitivity and number of different pigments suspended in the carrier liquid and the color light to which the suspension is exposed.

In FIGURE 2 there is shown one embodiment of the improved method and apparatus of this invention whereby a large broad area "tracking" contact is made by the blocking electrode with the imaging suspension **14** during the imaging process. Like numerals have been used to identify like elements throughout FIGURES 2–4 where they correspond with the elements of the FIGURE 1 device, and as can be seen from FIGURE 2, this device is identical with that of FIGURE 1 with the exception of the blocking electrode structure wherein a roller, generally designated **29**, is employed. This roller electrode **29** consists of a very soft central core **31** which may be of fairly high electrical conductivity. If a low conductivity core is used a separate electrical connection is made to the back of blocking layer **32**. This core may optionally and preferably be coated with a blocking electrode material **32**. The blocking electrode layer, if used, may be a separate replaceable layer which is either taped on the roller or held by mechanical fasteners or any other device which is capable of releasably holding the layer on the roller; or in the alternative, the layer may be integral with the roller itself, being either adhesively bonded, laminated, spray coated or the like on the surface of the roller. It a flat large area contact between the roller and the electrode **11** that the two be held together with sufficient force so that the roller material is compressed to provide a flat large area contact between the roller and the electrode **11**.

In FIGURES 3 and 4 two additional embodiments of the invention are illustrated except that the image projector has been left out of these figures to simplify the illustration. In the FIGURE 3 embodiment of the invention the same NESA glass electrode **11** with a coating of the imaging suspension **14** thereon is employed and is connected to a potential source **17** through a switch **18** as in the previous figures. The other side of potential source **17** is, however, connected to a pair of rollers **36** and **37** and a hold down platen **38** within an elongate endless belt blocking electrode generally designated **39**. This endless belt preferably is made up of a base layer **41** with a fairly high electrical conductivity so that the electrical potential applied to the inner rollers and hold down platen will be applied uniformly from this layer through the imaging suspension as the belt passes over electrode **11**.

As will the central core **31** of roller **29**, the substrate **41** of belt **39** may, for example, consist of any suitable material of relatively high conductivity. Typical conductive materials are conductive rubber, metal foils, of steel, aluminum, copper, brass or the like. Blocking electrode layer **42** may consist of Baryta paper (a paper coated with barium sulfate suspended in gelatin) or any other suitable blocking material as defined in copending application No. 384,680. Rollers **36** and **37** and hold down platen **38** may all be mounted on the same carriage so that movement of the carriage in the direction indicated by the arrow in the drawing will cause electrode belt **39** to roll or track over the surface of electrode **11** to make the desired contact. Hold down platen **38** may also be replaced with a plurality of rollers if desired so as to reduce friction while still pressing the belt surface downwardly during its passage over electrode **11**. Other modifications of the apparatus which will also produce a "tracking contact" of the endless belt **39** over electrode **11** will occur to those skilled in the art. Thus, for example, the two rollers and hold down platen may all be replaced with a reinforced block of material having a low coefficient of friction and having the shape as defined by the inside of the belt as seen in FIG. 3 and this block with the belt on its outer surface may simply be slid across electrode **11** so that the same type of tracking is caused to occur. Rotation of the belt in this instance would be caused by the frictional contact of the outer surface of the belt with electrode **11** and the low degree of frictional drag between the belt and the block which would tend to restrict its rotation around the block. In another modification the rollers may be provided with teeth running parallel to their axes adapted to engage ridges cut into the inner surface of the belt so as to provide a positive drive for the belt itself as it tracks over the electrode.

Referring now to FIGURE 4, there is seen a third embodiment of the invention in which the blocking electrode is supplied in the form of an elongate web **44** provided from a supply roll **46** and roller on a take-up roll **47** after use. This web is entrained over a number of small conductive rollers **48** each of which is connected to potential source **17** so as to provide a good source of electrical potential behind the web as it passes over electrode **11**. Rollers **48** along with supply and take-up reels **46** and **47**, respectively, are all journaled for rotation on a mounting plate **49**. A similar mounting plate may also be provided at the near end of these reels and rollers, as seen in FIG. 4, so that they will be journaled at both ends so as to make up a rigid carriage frame for the whole blocking electrode assembly. In operation this assembly is moved so as to track the blocking electrode **44** over electrode **11** by following path **51** shown in the figure in dotted line. In this way the blocking electrode web **44** will track over electrode **11**, be lifted up and return back to its

original position so that a new section of blocking electrode material will be provided for each pass of this electrode over electrode **11**.

Using any one of the embodiments of this invention, the blocking electrode may be passed over electrode **11** a plurality of times with cleaning between passes where required so as to produce improved resolution and more faithful color rendition.

In operation the photosensitive particle suspension is first coated on the conductive base electrode. This suspension may consist of any suitable type of photoresponsive particle in an insulating carrier liquid and may, for example, comprise any one of the imaging suspensions described in the aforementioned copending applications. After a thin coating of the imaging suspension has been applied, the voltage is applied to the tracking electrode and it is rolled into contact with the suspension and a full frame exposure is made. Any suitable voltage may be applied depending upon the thickness materials used to produce a preferred field strength of from about 400 to about 1,000 volts per mil across the suspension at the time of exposure. For example, using a 7 mil thick plastic coated Baryta paper over a conductive Neoprene (polychloroprene) backing on the tracking electrode with this electrode pressed down over the imaging suspension, it has generally been found that voltages of from about 1,000 to about 5,500 volts may be employed and that ordinarily better images are produced if the applied voltage is in the higher end of this range. It has further been found, however, that if the full voltage is applied as the blocking electrode is tracked into contact with the suspension that striations are produced in the final image, and if no voltage is applied the imaging suspension is squeegeed off electrode **11**. This effect may be completely eliminated, however, if the tracking electrode is closed over the whole image area with from about 800 to about 2,500 volts applied and then the voltage is raised to the full 4,000 to 5,000 volts to be employed for imaging. Different voltages may be used, of course, with different components of varying thickness to attain approximately the same field strengths in the system. At this time a full frame exposure of the image is made and the blocking electrode is rolled out of contact with the imaging suspension in exposed areas to reveal the final image on the base electrode. This image may then be fixed on the base electrode as by overcoating and used as a transparency or may be transferred to another surface and fixed thereon, as described in the copending applications referred to supra.

The invention having been generally described above, the following specific examples are given so as to further clarify the description of the invention. All parts in the examples are taken by weight unless otherwise indicated.

Examples I–VIII

In Examples I–IV, four different imaging suspensions are tested in an apparatus of the type illustrated in FIGURE 1; while in Examples V–VIII these same four suspensions are tested in an apparatus of the type illustrated in FIGURE 3. In both devices the base electrode is made up of NESA glass, as described above, and this NESA glass surface is connected in series with a switch, a potential source and the conductive portion of the blocking electrode. In the case of the FIGURE 1 example, it is connected to the conductive center of a roller having a coating of Baryta paper on its surface. The roller is approximately 2½" in diameter and is moved across the NESA plate at about 1.45 centimeters per second with an applied voltage of 2,500 volts. In the apparatus used for Examples V–VIII, a conductive Neoprene belt about 7¾" wide is entrained on 2" diameter steel rollers 7½" on center and a layer of plastic coated waterproof Baryta paper is taped over this belt. 1,500 volts is applied across the NESA glass and steel rollers while the belt is being rolled over the area of the suspension to be exposed, and when the belt has closed over the whole image area the voltage is raised to 4,500 volts and full frame exposure is made. In Examples I and V the imaging suspension consists of 7 parts by weight of photosensitive particles in Sohio odorless solvent 3440. These particles are made up of equal parts by weight of metal-free phthalocyanine, Watchung red B [a barium salt of 1 - (4' - methyl - 5' - chloroazobenzene - 2' - sulfonic acid) - 2 - hydroxy - 3 - napthoic acid] C.I. 15,865 and Algol Yellow G.C. [1,2,5,6 - di(C,C' - diphenyl) - thiazole - anthraquinone, C.I. 67,300.] In Examples II and VI the 7 parts by weight of particles include equal parts of metal-free phthalocyanine, Watchung red B and 8,13-dioxodinaptho(2,1 - b;2',3' - d) - furan - 6 - carbox - p-methoxyanalide. In Examples III and VII the particles are all metal-free phthalocyanine and in Examples IV and VIII the particles are all 2,9-dimethylquinacridone. In running tests with these suspensions on the two different imaging devices, they are run at various levels of light intensity to determine the lowest light intensity which will produce a good quality image on each. The minimum light intensity which will produce an image of equivalent quality in Examples V–VIII is about 1/20 the minimum light exposure required for Examples I–IV.

What is claimed is:

1. A method of photoelectrophoretic imaging comprising depositing a thin layer of an imaging suspension made up of photoresponsive particles suspended in an insulating carrier liquid on a smooth surface transparent electrode, tracking a relatively large flat surface area of a movable second electrode into broad area pressure contact with the suspension on said first electrode, applying an electrical field across said electrode and exposing at least a part of said suspension between said two electrodes with electromagnetic radiation which is actinic to at least some of the particles in said suspension, and then tracking said second electrode off said suspension whereby a high quality image is rapidly produced on said first electrode.

2. The method of claim **1** wherein said particles are of one color and a monochromatic image is formed.

3. The method of claim **1** wherein said imaging suspension comprises particles of at least two colors and a polychromatic image results.

4. The method of claim **1** wherein said second electrode comprises a compressible material and said second electrode is brought into broad area contact with said imaging suspension.

5. The method of claim **1** wherein said second electrode comprises an endless belt and wherein a large area of said belt is brought into broad area contact with said imaging suspension.

6. The method of claim **1** wherein said second electrode comprises an elongate web and wherein a large area of said web is brought into broad area contact with said imaging suspension.

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