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2,859,352

ELECTORADIOGRAPHY

Filed June 23, 1955

2 Sheets-Sheet 1

FORM X-RAY IMAGE OF
OBJECT ON CHARGED
PHOTOCONDUCTIVE
COATING

DEVELOP ELECTROSTATIC
IMAGE FORMED BY AND
CORRESPONDING TO X-RAY
IMAGE ON PHOTOCONDUCTIVE
COATING.

FIX DEVELOPED
ELECTROSTATIC IMAGE
TO PHOTOCONDUCTIVE
COATING

Fig. 1

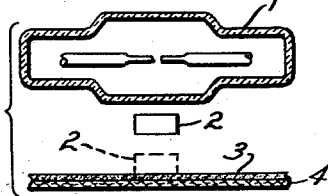


Fig. 2

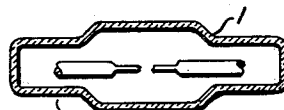
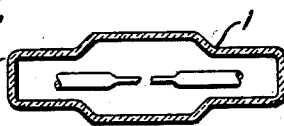


Fig. 4

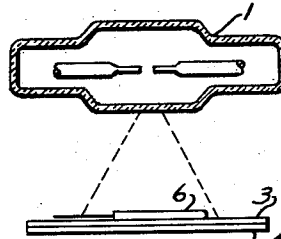


Fig. 3B

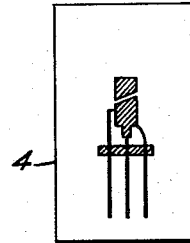


Fig. 3C

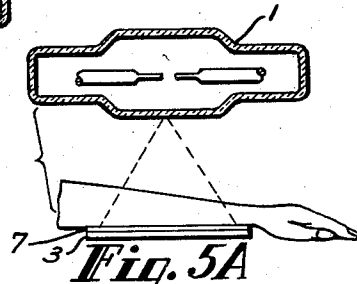


Fig. 5B

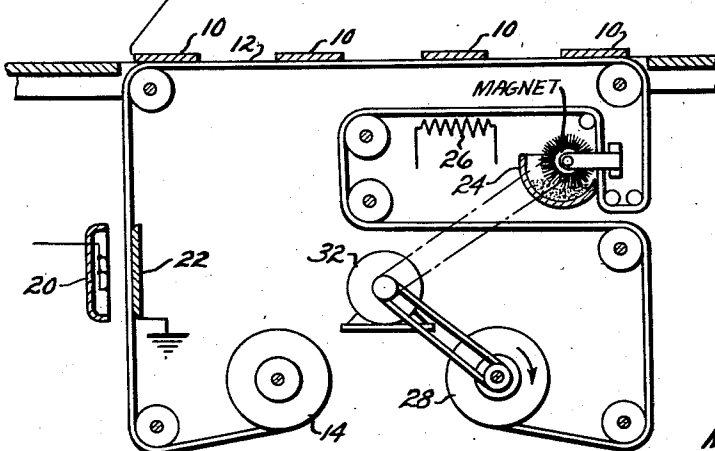


Fig. 6

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2 Sheets-Sheet 2

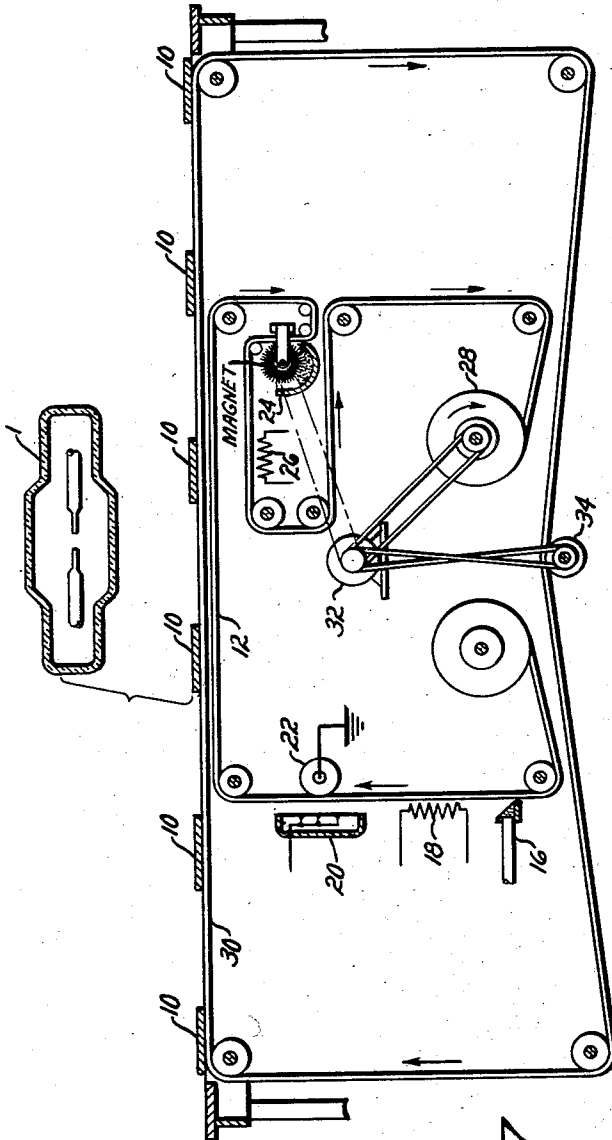


Fig. 7

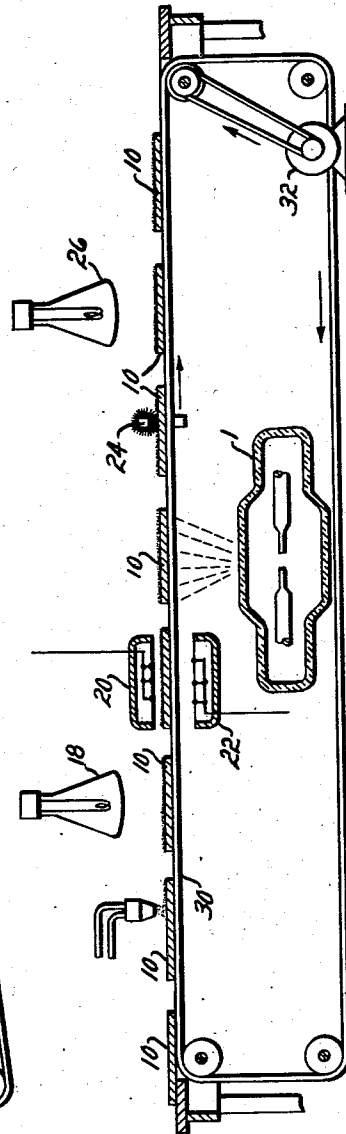


Fig. 8

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2,859,352

ELECTRORADIOGRAPHY

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Application June 23, 1955, Serial No. 517,476

5 Claims. (Cl. 250—65)

This invention relates to improved methods and means for making radiographs (graphic recordings of X-ray images) electrophotographically. More particularly, the invention relates to improved electrophotographic methods and means for electroradiography employing a novel X-ray sensitive photoconductive material.

Previously radiographs or X-ray prints have normally been made on chemically developed film. X-ray processes using such film are expensive and time consuming. Furthermore, the methods using film require wet processes for developing and making prints. Often it is necessary to wait several hours before a usable print is obtained. Normally, in order to save time in obtaining usable results, the exposed negative is examined directly. The black-for-white reversed image involved is much more difficult to interpret than a direct positive image, such as that normally provided according to this invention.

It is therefore an object of this invention to provide improved methods and means for electroradiography.

A further object of the invention is to provide improved methods and means for producing usable radiographic prints directly upon an expendable X-ray sensitive material without the necessity of an intermediate dry or wet transfer step.

Another object of the invention is to provide improved methods and means for directly producing usable radiographic prints quickly and economically.

Still another object of the invention is to provide improved methods and means for directly producing a usable radiographic print on the object itself which is being inspected by X-rays.

Another object of the invention is to provide improved methods and means for directly producing usable radiographic prints within a few seconds after exposure without the necessity of an intermediate transfer step.

Yet another object of the invention is to provide improved methods and means for directly and continuously producing usable radiographic prints of a series of objects.

These and other objects and advantages of the invention are realized by a rapid dry process for directly making immediately usable radiographs. No transfer steps are necessary. In contrast to other dry electroradiograph systems using photoconductive selenium plates, for example, the X-ray sensitive material of the present invention does not require a transfer step, and does not require a special master plate which must be exposed over and over again, and cleaned between successive usages. In accordance with the invention, X-ray sensitive photoconductor-resin mixtures may be coated on paper, plastic, or metal sheets, for example, or directly upon the object to be examined. An example of such a material is finely divided ZnO dispersed in a silicone resin binder. An X-ray image of an object when formed on such a coating results in an electrostatic image corresponding to the X-ray image. The electrostatic image may be developed with a finely divided developer powder and fixed, as by

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heating, or spraying with a quick-drying adhesive material.

The invention will be described in greater detail by reference to the accompanying drawing wherein:

5 Figure 1 is a diagram illustrating the steps of one method for carrying out the processes of the invention;

Figure 2 is a sectional, elevational view of one embodiment of apparatus in accordance with the invention for producing an X-ray image of an object on an X-ray sensitive photoconductive coating according to the invention;

10 Figure 3a is an elevational view of a completely assembled (potted) junction transistor whose internal structure is not visible to the unaided eye;

Figure 3b is a sectional, elevational view of apparatus 15 for forming an X-ray image on an X-ray sensitive photoconductive coating of the internal structure of a transistor such as shown in Figure 3a;

Figure 3c represents a developed electroradiograph of the internal structure of the transistor shown in Figure 3a;

20 Figure 4 is a sectional, elevational view of another embodiment of the invention for producing an X-ray image on a photoconductive coating according to the invention;

Figure 5a is an elevational view of another embodiment 25 of the invention wherein an X-ray image of the bone structure of the human arm is formed on an X-ray sensitive photoconductive coating directly upon the outer skin of the arm being X-rayed;

Figure 5b shows a developed electroradiographic print 30 of the bone structure of the human arm shown in Figure 5a;

Figure 6 is a partially schematic, elevational view of another embodiment of the invention for making radiographs of objects in a continuous process wherein the 35 objects themselves are carried by an X-ray sensitive photoconductive-coated conveyor sheet;

Figure 7 is a partially schematic, elevational view of another embodiment of the invention for making radiographs in a continuous process on an X-ray sensitive 40 photoconductive-coated conveyor sheet; and

Figure 8 is a partially schematic, elevational view of still another embodiment of the invention for making radiographs in a continuous process directly upon the 45 objects being inspected.

Similar reference characters are applied to similar elements throughout the drawing.

It is known that certain photoconductive materials may be employed to produce visible images by taking advantage of the electrical response of such materials to radiations such as visible light. Such materials may be 50 charged electrostatically so as to hold a uniform electric charge. A charged layer of such a material, when exposed to light, will release its charge at whatever points the light impinges thereon by becoming more electrically conductive at these points. Thus, a latent electrostatic charge pattern corresponding to the incident light image is formed on the coating. The intensity of the residual charge in different portions of the charge pattern is proportional to the intensity of the light received from 55 different portions of the light image. This invisible latent electrostatic charge pattern may be rendered visible by developing with an electrically charged electroscopic powder which is attracted to and held by the charge pattern. This powder may be permanently fixed to the coating by 60 heating, solvent action, supplementary adhesives, or other techniques.

The photoconductive coating according to the invention comprises a finely divided photoconductive material dispersed in an electrically-insulating film-forming vehicle. 70 It has been found that the materials according to the invention, in addition to being electrostatically responsive to light, are also sensitive to X-rays and may be em-

ployed to excellent advantage for almost instantaneously providing radiographs. According to the invention, the photoconductive material may be coated on paper sheets or rolls, metal or plastic films, glass plates or any other mechanically suitable surfaces to which the coating will adhere. Because of its cheapness, paper is preferred. As another important feature of the invention, the X-ray sensitive photoconductive material may be coated directly upon the object to be inspected radiographically.

The mixture used to produce the photoconductive coating may include a solvent or the mixture may be thermoplastic. The mixture may be coated by any convenient coating method, for example, by rolling on with a roller, by screening with a silk or metal screen, by brushing, by whirling, by spraying, or by stamping. After the mixture is coated, it is dried, for example by evaporation of the solvent, or by cooling if the mixture is thermoplastic. Where the coating is dried by evaporation, heat may be applied to accelerate the drying process. Similarly, the coating may be chilled where the mixture is thermoplastic and is applied hot.

When the photoconductive coating is produced on a backing of highly insulating material such as glass or high resistivity plastics, the backing may be treated so as to render its surface electrically conducting. This furnishes a plane immediately below the coating capable of being placed at ground or other desired potential in order to facilitate charging with a blanket electrostatic charge before exposure. This plane may be "floating" (isolated in potential) during all stages of image production other than charging. Preferably a double corona discharge is employed to provide ions of opposite charge on opposite sides of the coated insulating base so as to obviate the necessity of rendering a surface of the insulating base conductive.

X-RAY SENSITIVE PHOTOCONDUCTIVE MATERIALS

Examples of suitable mixtures for producing an X-ray sensitive photoconductive coating are as follows:

Example 1.—A mixture of 80 grams of a 60% solution in xylene of silicone resin GE-SR-82, marketed by the General Electric Company, Silicone Products Division, Waterford, New York, 106 grams of toluene and 120 grams of photoconductive white zinc oxide is ball-milled for about three hours and then applied to the fixed form as described above.

Example 2.—A mixture comprising 100 grams of powdered photoconductive lead iodide, 100 milliliters of toluene and 60 milliliters of a 60% solution of a silicone resin (SR-82, source as above) in xylene is ball-milled until the lead iodide is thoroughly dispersed in the plastic-solvent mix and is coated as described above.

Example 3.—A mixture comprising 100 grams of finely ground photoconductive cadmium sulfide and 150 grams of a 35% polystyrene solution in toluene is thoroughly mixed for about 5 minutes in a high speed blender and coated as described above.

Example 4.—A mixture comprising 60 grams of a 35% solution of polyvinyl acetate resin in methanol, 40 grams of CP dry process white zinc oxide and 20 milliliters of acetone is ball-milled for about one hour and then coated as described above.

Example 5.—Equal parts by weight of CP photoconductive white zinc oxide and melted paraffin are intimately mixed and then the molten mixture applied as described above and then allowed to cool.

Example 6.—A mixture of three parts by weight of CP photoconductive white zinc oxide and one part by weight of carnauba wax are melted together and then coated as described above and then allowed to cool.

Example 7.—Three parts by weight of CP photoconductive white zinc oxide and one part by weight of carnauba wax are dissolved in toluene and then coated as described above.

Example 8.—Two parts by weight of CP photoconductive white zinc oxide and one part by weight of methyl cellulose are dispersed in a suitable solvent and then coated as described above.

Example 9.—Seven parts by weight of CP photoconductive white zinc oxide are dispersed in ten parts by weight of a 10% solution of a vinyl chloride, vinyl acetate copolymer resin in acetone. The mixture is thinned with acetone to the desired consistency and then coated as described above.

Example 10.—Ten grams of dry shellac are dissolved in 180 cc. of methanol and 20 cc. of acetone. 100 grams of this solution is mixed with 50 grams of CP photoconductive white zinc oxide and then coated as described above.

It was found that a mixture of zinc oxide and lead iodide had a greater sensitivity to X-rays than either material alone according to the examples above described. This mixture comprised about 10 grams of PbI_2 to 90 grams of ZnO in the mixture.

FILM-FORMING VEHICLES

The electrically-insulating, film-forming vehicle is an essential part of the composition and may be chosen from any one of a number of substances. A preferred film-forming vehicle has a high dielectric constant and a high dielectric strength. These materials may be natural or synthetic resins or waxes. Examples of suitable resins are the vinyl resins, silicone resins, phenol-formaldehyde compositions, cellulose esters and cellulose ethers. Shellac is an example of a natural material. Examples of suitable waxes are paraffin, carnauba wax and beeswax. Inorganic binders such as sodium silicate may also be used. Mixtures including one or more vehicles may be used.

The photoconductor may be suspended in the vehicle in any of several ways. A simple way is to dissolve the film-forming vehicle in an organic solvent capable of effecting the solution and then dispersing the powdered photoconductor thereon. Alternatively the photoconductor may be dry blended by kneading with the film-forming vehicle heated to a sufficiently high temperature to be rendered plastic. In this case of waxes they may be melted and the photoconductor mixed with the melt.

The proportion of powdered photoconductor to film-forming vehicle in the final coating may vary over a wide range. The preferred ranges are 50 to 90% of photoconductor and 50 to 10% of film-forming vehicle. The optimum proportions will be based upon the nature of the photoconductor, the film-forming vehicle and the results desired.

The speed of response of the photoconductive coating is partially dependent upon the nature of the photoconductor material, the nature of the film-forming vehicle and the ratio by weight of the film-forming vehicle to that of the photoconductor. Since the speed of response depends on a balance of characteristics of these factors, almost any desired response may be obtained by a proper selection of materials and compositions.

A proper selection of materials and compositions will also designate how long an electrostatic image may be stored, since storage of the electrostatic image depends at least in part upon the resistivity of the coating. Generally the higher the resistivity of the coating the longer the storage time.

DEVELOPER MATERIALS AND APPLICATION

The developer powder may be applied in any of a number of ways such as by spraying, dusting, or brushing. For application by brushing a convenient brush comprises a mixture of magnetic carrier particles, for example, powdered iron and the developer powder. The mixture is secured in a magnetic field to form a developer brush. This method of development is more completely described by H. G. Greig in U. S. Patent application, Serial No. 344,123, filed March 23, 1953. A camel's hair-

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or other brush comprised of bristles having suitable triboelectric properties to impart the desired charge to the powder may also be used.

A preferred carrier material for the developer mix in the magnetic developer system consists of "alcoholized iron," that is, iron particles free from grease and other impurities soluble in alcohol. These iron particles are preferably relatively small in size, being preferably in their largest dimension about .002" minimum to .008" maximum. Satisfactory results are also obtained using a carrier consisting of iron particles of a somewhat wider range of sizes up to about .001 to .020".

Other developing techniques are available and may be employed to advantage in any of the embodiments of the invention described. One method in particular may actually be preferred because of the sharply outlined images produced thereby. This technique is termed "cascade" development and is fully described by Robert C. McMaster in an article entitled "New Developments in Xeroradiography" published in the Journal of the Society for Nondestructive Testing Summer Number, 1951. In this technique the developing powders, consisting of a mixture of fine pigment particles and a coarse granular carrier material, are cascaded over the surface of the exposed plate in a rocking developing tray, for example. The images produced by this technique are high-contrast, sharp-line types rather than those of large areas of nearly constant density. Such images, of course, are highly desirable for some applications in radiography. This is particularly true where it is desired to accentuate small, but abrupt, changes in image density.

Another method which may be employed to develop the latent electrostatic images is placing the exposed photoconductor in an environment consisting of a cloud of electrically charged particles of powder. This technique is also described in the aforementioned article by McMaster.

A preferred developer powder may be prepared as follows: A mixture comprising 200 grams of 200 mesh Piccolastic resin 4358 (an elastic thermoplastic resin composed of polymers of styrene, substituted styrene and its homologs) marketed by the Pennsylvania Industrial Co., Clairton, Pa., 12 grams of Carbon Black 6, marketed by the Eimer and Amend Co., New York, N. Y., 12 grams of spirit Nigrosine S. S. B., marketed by the Allied Chemical and Dye Co., New York, N. Y., and 8 grams of Iosol Black, marketed by the Allied Chemical and Dye Co., New York, N. Y., are thoroughly mixed in a stainless steel beaker at about 200° C. The mixing and heating should be done in as short a time as possible. The melt is poured onto a brass tray and allowed to cool and harden. The hardened mix is then broken up and ball-milled for about 20 hours. The melted powder is screened through a 200 mesh screen and is then ready for use as a developer powder. This powder takes on a positive electrostatic charge when mixed with glass beads or iron powder. It therefore develops an electrostatic image composed of negative charges. 2-4 grams of the developer powder and 100 grams of the magnetic carrier material are blended together giving the completed developer mix. Other ratios may be used.

The developer powder may be chosen from a large class of materials. The developer powder is preferably electrically charged to aid in the development of the electrostatic latent image. The powder may be electrically charged because the powder (1) is electroscopic, or (2) has interacted with other particles with which it is triboelectrically active, or (3) has been charged from an electric source such as a corona discharge. Examples of other suitable developer powders are sulphur, natural and synthetic resins or mixtures thereof.

THE ELECTORADIOGRAPHIC PROCESS

Referring to Figure 1, the steps of the method of the invention comprise the formation of an X-ray image of

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an object to be examined on a blanket-charged photoconductive coating. This coating may be on a suitable backing such as paper or cellophane, metal, or glass, or upon the object itself. The X-ray image causes the photoconductive coating to become more conductive at the points receiving the radiation so that the charge at these points leaks off. Thus, the charges remaining (i. e., the "dark" areas not receiving X-rays) constitute a latent electrostatic image on the coating corresponding to the intensities in the X-ray image. This electrostatic image is then developed by applying a finely divided tone powder thereto. The powder deposits in densities proportional to the charge pattern, and may be fixed in place by a suitable method, such as by heating.

ELECTORADIOGRAPHIC APPARATUS

Referring to Figure 2, an object 2 which is to be inspected is shown as being located between the X-ray apparatus 1 and the photoconductive plate 4. The X-ray apparatus is adapted to irradiate the object 2 with X-rays and to project an X-ray image thus formed upon the X-ray sensitive photoconductive coating 3 which has previously been charged with a uniform electrostatic charge. As is well known in radiography the precise distance of the object with respect to the X-ray source is not critical for focusing purposes if the X-ray source is a substantially point source as preferred in this and other embodiments of the invention. In general the distance of the object from the point source of X-rays and from the image plane determines only the enlargement of the image of the object from impingement of unabsorbed radiation from the X-ray source. Hence, the object 2 may be irradiated with X-rays whether spaced between the X-ray source 1 and the photoconductively coated plate 4 or placed directly on the plate as shown by dotted lines.

The sensitivity of the photoconductive coating may be appreciably improved by employing a metallic backing plate or intensifying screen just as in present radiography practice. The intensity of radiation is increased by such a plate due to the secondary emission of X-rays reflected back to the X-ray sensitive coating.

A latent electrostatic image is formed on the photoconductive coating 3 which corresponds to the X-ray image. After exposure the plate may then be removed and brushed, for example, with a finely divided developer as previously described to render the electrostatic image visible.

Referring to Figures 3a, 3b, and 3c, a typical use of the invention is illustrated. Figure 3a depicts the normally visual appearance of a potted junction transistor. Such devices are normally encased or potted in a small metallic cylinder or can or in a solid opaque block of a plastic such as a polymerized epoxy resin. The internal contents and structure thereof, of course, cannot be visually examined after the device is so potted. Usually such completed articles, if inoperative or defective, must be dis-assembled to determine the defect. According to the invention, a transistor such as shown in Figure 3a may be radiographed as shown in Figure 3b. In this embodiment the transistor 6 is shown as lying upon the charged X-ray sensitive photoconductive coating 3. After irradiation with X-rays and the development and fixing of the electrostatic image of the internal contents of the transistor formed thereby, a radiographic print is obtained as illustrated in Figure 3c. The total time involved in obtaining a completed print after exposure is only a few seconds. As shown in Figure 3c, the transistor 6 is inoperative due to a lateral crack in the germanium wafer. Thus, the defect causing inoperativeness is quickly and economically discovered. Alternatively, the radiographic print of the internal structure of the transistor can be made directly upon the external casing thereof by employing the technique described hereinafter in connection with Figure 4. Due to the low cost of the requisite materials according to the invention, and the easy and rapid processing in-

volved, it is feasible for the first time to make radiographic prints of each completed transistor or other articles of manufacture at the end of an assembly line production to detect possible defects such as thus described.

ELECTRORADIOGRAPHIC PRINTING ON X-RAYED OBJECTS

Figure 4 illustrates an important embodiment of the invention wherein the object 2 to be inspected by X-rays from the X-ray apparatus 1 is coated itself with the photoconductive material 3. Since the radiograph of the object 2 is to be formed actually on the object itself, the coating of photoconductive material is applied to the side of the object remote from the X-ray source and is then charged. Thus, the object actually is interposed between the X-ray source and the photoconductive coating. The X-ray image formed upon irradiation of the object in turn forms a latent electrostatic image upon the coating. This electrostatic image is rendered visible as before by applying a finely divided developer thereto. The developed image may be fixed in place as by heating, or may be removed, for example, by blowing off, or by brushing with a magnetic brush after dispersing the charge holding the powder image, for example, by exposure to light, and the coating re-used immediately or at a future time by re-charging, re-exposing with X-rays or visible light, and re-developing. Additional images may also be added by incidence of additional images of suitable spectral characteristics on non-image portions of the coated area.

By using the method of coating the object as illustrated in Figure 4, many advantages heretofore unobtainable with any previously known X-ray process may be realized. A radiograph of the contents of any opaque container may thus be printed upon the surface of the container showing not only the structure therein but also the shape, size, and position. This embodiment of the invention may be practiced to advantage in other applications such as in detecting flaws in metals which have been cast or machined. Here a radiograph showing the flaws may be printed directly upon the metal itself where the flaw occurs. As pointed out in connection with Figures 3a, 3b, and 3c the internal structure of devices such as a transistor showing size, position and defects, if any, can be printed directly upon the opaque casing in an assembly line technique.

Another important use of the embodiment wherein the X-ray sensitive photoconductive coating is applied directly to the object to be radiographed is in the field of medicine. Referring particularly to Figure 5a, a human arm is depicted which may have a bone fracture, for example. Heretofore prior to the setting of the bones it was necessary to X-ray the arm using chemically-developed film. After development of the film, which may consume several hours, the bone could properly be set by referring to the film. Furthermore, it is often desirable to have an indication on the limb itself representing the direction and location of the fracture. By prior methods this was accomplished by referring to the X-ray film in order to manually draw with an indelible pencil the approximate location and direction of the fracture. Finally, after the fractured arm or leg has been set, a cast is often placed thereon.

As shown in Figure 5a, the photoconductive coating may be applied directly onto the arm or to the outside of the cast on the side opposite the side to be exposed to X-rays. In order to charge the photoconductive coating 3 it is necessary to provide a conducting path to ground immediately below the photoconductive coating. The skin itself may be sufficiently conductive to provide this ground. Other additional grounding means may be easily and cheaply provided by first coating the skin surface with a thin film 7 of a colloidal graphite dispersion such as one of the "Dag" dispersions marketed by the Acheson Colloid Company, Port Huron, Michigan. Likewise silver platelet suspensions or other conducting

paints may be employed. The X-ray image thus formed on the photoconductive coating results in an electrostatic image which may be developed and fixed directly upon the arm itself or upon the cast. As shown in Figure 5b a radiograph 5 is thus obtained directly upon the member X-rayed showing not only the extent of the fracture but also its direction and location. Such a print is available within seconds after exposure to the X-rays. If it is desired to keep the area available for further radiographs, the fixing step may be omitted and after the fracture has been set the photoconductive coating with its visible image may be removed as by blowing off, by erasing with a magnetic brush after light exposure, or by washing with water or alcohol. To make later radiographs either on the arm or a cast it is only necessary to re-charge the photoconductive material and re-expose and develop.

ELECTRORADIOGRAPHIC CONTINUOUS PROCESSES

Referring now to Figure 6, a continuous process of electradiography is shown for printing radiographs of a continuous series of objects 10 directly upon an X-ray sensitive photoconductive tape 12 which carries the objects. The paper which is coated with X-ray sensitive photoconductive material is supplied by the roll 14. This paper may comprise any grade of paper of reasonable strength. The coating comprises a finely divided photoconductive material dispersed in an electrically-insulating film-forming vehicle such as previously described.

The first operation is that of depositing a blanket electrostatic charge upon the photoconductive coating by means of the corona discharge apparatus 20 and a grounded metal plate 22. The paper passes between the corona discharge apparatus 20 and the grounded metal plate 22 which is necessary to aid in establishing the electric field necessary to produce a corona discharge. A grounded conductive roller may be used instead of the plate 22. The corona discharge apparatus may comprise three .003" diameter wires placed about 0.5" apart and about 0.5" from the surface to be charged.

The objects 10 to be electradiographed are then placed on the charged photoconductive surface of the paper 12 and as the objects and the paper pass beneath the X-ray source 1 they are irradiated thereby. The X-ray image of the objects thus formed on the X-ray sensitive photoconductive coating in turn forms a latent electrostatic image corresponding thereto.

After exposure to the X-rays the objects may then be removed while the paper continues to travel to the developing station. The latent electrostatic images formed on the coating are brushed with a rotary magnetic brush 24. The magnetic brush may comprise a rotatable, circular magnet having attached thereto a mixture of finely divided magnetic carrier particles and finely divided developer particles. As the brush contacts the electrostatic images, the developer powder particles adhere thereto in a pattern corresponding to the electrostatic image. It is preferred to use the previously described developer mix which includes a thermoplastic developer powder.

After development the paper with its developed images thereon passes a heat source 26 which applies heat to the developed images, fusing the images and causing them to adhere to the photoconductive coating, thereby fixing the developed images to the paper 12. The heat source 26 may comprise a resistance heater or an infrared lamp. Thereafter the paper is wound upon a take-up reel 28.

A permanent radiographic record thus is obtained of each object coming off an assembly line production-type process, for example. In order to identify each object with its respective radiograph, X-ray opaque indicia may be placed on the objects so as to not obscure the structures thereof. An alternative indicia marking means takes advantage of the fact that the photoconductive ma-

terial is also light-sensitive. Thus the index information may be added by exposing the photoconductive coating at some convenient point to a visible light image using a suitable optical arrangement.

Another embodiment of the invention is shown in Figure 7 wherein a continuous series of objects 10 may be electroradiographed upon an X-ray sensitive photoconductive tape 12. In this embodiment the objects are not carried upon the X-ray sensitive tape itself but are transported by means of an X-ray transparent belt 30. Thus as the objects 10 are carried past the X-ray source 1, the X-ray images formed thereby are focused upon the X-ray sensitive paper which is being transported directly beneath the X-ray transparent belt 30. As before the X-ray sensitive paper 12 may be supplied already coated from the reel 14. Alternatively the paper may be fed uncoated past a coating-application trough 16 and coated thereby and then dried as it passes the heating source 18. Either an infrared lamp or an electrical resistance element may comprise the heating source 18. Other rapid drying means may be employed. Charging may be accomplished by means of a grounded metal roller 22 instead of but for the same purpose as the grounded plate described in connection with Figure 6. After the formation of the latent electrostatic image corresponding to the X-ray images, the paper is transported past the developer 24 and the fixer 26. This embodiment is especially advantageous where the weight of the objects to be electroradiographed is too great to be supported by the X-ray sensitive paper itself. In order to form sharp X-ray images of the objects upon the X-ray sensitive paper, the travel speed of both the conveyor belt 30 and the paper 12 must be substantially the same. Otherwise due to the movement of the objects 10 at a different rate with respect to the movement of the paper 12 during image formation blurring would occur. The synchronization of the belt conveyor 30 and the X-ray sensitive paper 12 may be accomplished by driving both the conveyor and the paper from the same motor 32 by like-diameter pulleys on the same motor shaft, and like-diameter pulleys on the paper take-up reel 28 and the conveyor belt driver 34. The X-ray transparent belt 30 may be made from any suitable X-ray transparent material having sufficient strength to support objects of given weights. An example of such a material is plasticised plastic-laminated fiberglass or cloth, or a thin aluminum or stainless steel belt. A sufficient intensity of X-rays to penetrate the belt completely should be employed.

In this embodiment a permanent radiographic print of each object is obtained. As explained before, the identification of a particular object with its image may be accomplished by placing X-ray opaque indicia upon the objects in some convenient location so as to not obscure any of the structure of the objects or by exposing to a visible light image of the indexing information.

Referring to Figure 8, a continuous process is shown for printing radiographs directly upon the objects to be examined by X-rays. The objects 10 are carried upon a continuous X-ray transparent conveyor 30 which may be made of any suitable X-ray transparent material sufficiently strong enough to support the objects. The conveyor 30 first carries the objects past a spray nozzle 16 which sprays the photoconductive coating completely over the upper surface of the objects. This coating comprises a finely divided photoconductive material dispersed in electrically-insulating film-forming vehicle such as previously described.

The photoconductive coated objects are then fed past an infrared lamp 18 or other heating means where the coating is dried. The next operation is that of depositing a blanket electrostatic charge upon the photoconductive coating on each object by means of the corona discharge apparatus 20 and 22 such as described previously. If the objects themselves are electrically conduct-

ing, a single corona discharge is sufficient. However, if the objects are relatively thin and flat but not electrically conductive, a second corona apparatus 22 furnishing a blanket charge of opposite electrical sign on the reverse side of the object may be aligned opposite the corona unit 20. The objects thus pass between the corona discharge apparatus 20 and the corona discharge apparatus 22 which is necessary to aid in establishing the electrical field necessary to produce a uniform surface charge.

The objects are thereafter passed over the X-ray source 1 and irradiated with X-rays therefrom. The X-ray image of the objects are thus formed on the X-ray sensitive coating on the objects themselves and these X-ray images in turn form latent electrostatic images corresponding thereto on the photoconductive coating on the objects.

The latent electrostatic images formed on the coatings on each object are then brushed with a rotary magnetic brush 24, or developed by other suitable means such as have been described. The magnetic brush (which may comprise a rotatable cylindrical magnet having attached thereto a mixture of finely divided magnetic carrier particles and finely divided developer particles) contacts the electrostatic images on the objects. The developer powder particles adhere to the images in a pattern corresponding thereto. Preferably a developer may be employed which includes a thermoplastic developer powder.

The last operation is performed as the conveyor 30 carries the objects with their developed images thereon past an infrared lamp 26 which fuses the images and causes them to adhere to the photoconductive coating on each object. The developed images are thereby permanently fixed to the objects themselves.

It has been found that the exposure time for the X-ray sensitive photoconductive materials such as zinc oxide or lead iodide is of the same order of magnitude as the exposure time of industrial X-ray film (type M, such as supplied by Eastman Kodak Co., Rochester, New York, for example).

It should be understood that the various charging techniques described are interchangeable and are primarily dependent upon the electrical characteristics of the material which is coated photoconductively. In general if the objects to be radiographed according to the invention are thin but not electrically conductive the double corona discharge apparatus described in connection with Figure 8 is to be preferred.

There thus has been described economically inexpensive methods and means for making radiographic prints either on a separate recording medium or upon an object being inspected radiographically. Many modifications of the invention may be made, as has been demonstrated, without departing from the scope of the invention. Because of the demonstrated versatility of the novel X-ray sensitive material according to the invention, many uses heretofore impossible or impractical may be realized. The instant specification has representatively illustrated the range of possible applications of the instant invention.

What is claimed is:

1. A method of electroradiography comprising the steps of: exposing an electrostatically charged object to be electroradiographed having an X-ray sensitive coating thereon to an X-ray image of said object, said coating consisting at least of a finely-divided photoconductive material dispersed in an electrically-insulating film-forming vehicle, and developing said electrostatic image.

2. A method of electroradiography comprising the steps of: coating at least one side of an object to be electroradiographed with a finely-divided photoconductive material dispersed in an electrically-insulating film-forming vehicle, providing said coating with a blanket electrostatic charge, irradiating the side of said object which is uncoated and opposite said coated side with X-rays whereby the X-ray image of said object which is

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thereby formed on said coating produces a latent electrostatic image corresponding to said X-ray image, and developing said electrostatic image.

3. Electroradiograph apparatus comprising an X-ray transparent conveyor adapted to transport objects to be electroradiographed, means adjacent said conveyor for coating at least one side of each of said objects on said conveyor with a finely-divided photoconductive material dispersed in an electrically-insulating film-forming vehicle, means adjacent said conveyor for electrostatically charging said coating on said objects, X-ray means adjacent said conveyor for forming an X-ray image of each of said objects on said coating of each object as said objects are carried thereby, each of said X-ray images forming on said coating of each of said objects a latent electrostatic image corresponding to said X-ray image thereon, and means adjacent said conveyor for developing said electrostatic images as said conveyor passes thereby.

4. Electroradiograph apparatus comprising an X-ray transparent conveyor adapted to transport objects to be electroradiographed, means adjacent said conveyor for coating at least one side of each of said objects on said conveyor with a finely-divided photoconductive material, means adjacent said conveyor for electrostatically charging

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ing said coating on said objects, X-ray means adjacent said conveyor for forming an X-ray image of each of said objects on said coating of each object as said objects are carried thereby, each of said X-ray images forming on said coating of each of said objects a latent electrostatic image corresponding to said X-ray image thereon, means adjacent said conveyor for developing said electrostatic images with a finely-divided developer as said conveyor passes thereby, and means for fixing said developed images.

5. The method of claim 2 wherein said photoconductive material is zinc oxide.

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