

March 24, 1959

E. H. LEHMANN

2,879,397

IMAGE DEVELOPMENT

Filed Dec. 19, 1955

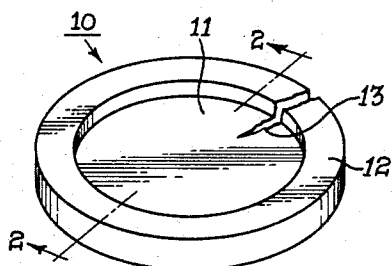


Fig. 1



Fig. 2

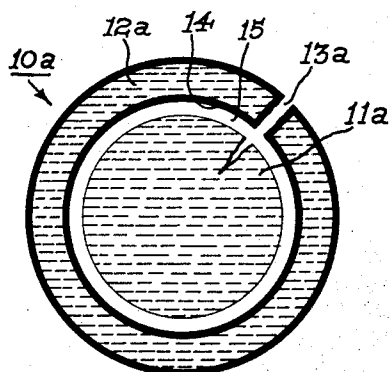


Fig. 3

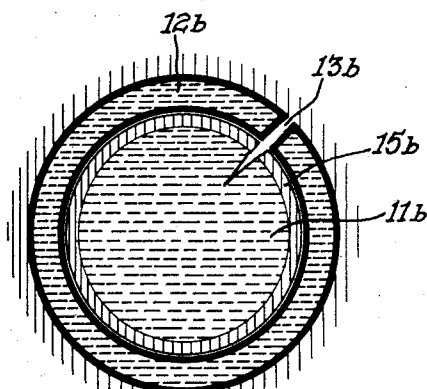


Fig. 4

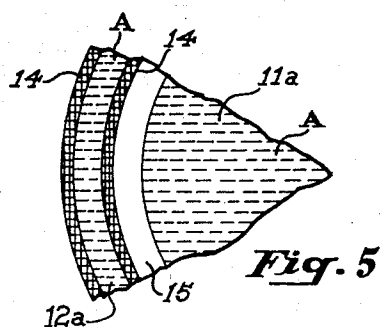


Fig. 5

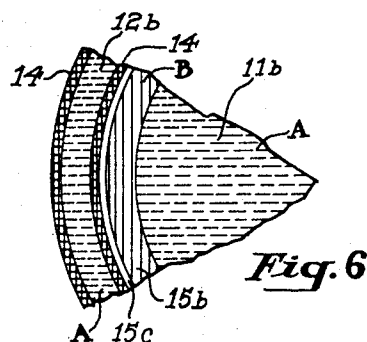


Fig. 6

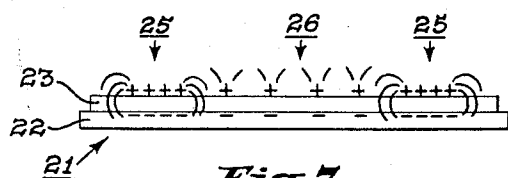


Fig. 7

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IMAGE DEVELOPMENT

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Application December 19, 1955, Serial No. 554,068

6 Claims. (Cl. 250—65)

This invention relates in general to X-ray recording and in particular to a new improvement in X-ray recording by xerography.

The art of X-ray recording by xerography, generally known as xeroradiography, relates to the recording of X-ray patterns and information by means of materials and devices whose electrical conductivity is altered by the action of penetrating radiation, such as X-rays and the like. It has been found that a normally insulating X-ray sensitive layer overlying a conductive backing surface may be charged electrically and used as a radiation sensitive recording surface because of conductivity imparted by the radiation. Thus, the appropriate surface, such as for example a metallic surface having a vitreous or amorphous selenium layer, may be charged and exposed to an X-ray pattern, as disclosed in Schaffert et al. 2,666,144. The result of this charging and exposure is an electrostatic latent image or xeroradiographic latent image which may be developed by dusting with finely divided charged particulate material to form a visible image.

In present operations, according to the art of xeroradiography, it is usual to charge and expose an appropriate xeroradiographic plate, after which the image is developed by presenting to the plate surface a cloud or gas suspension of charged powder particles. The image as developed in this way is characterized by a property known in the art as "halo," in which discontinuities in the charge or potential of the xeroradiographic latent image are accentuated in the development process. Thus, areas having a high charge are developed by the deposition thereon of a moderately larger amount of powder, and areas having a lower charge are developed by a moderately lighter powder deposition, while in boundaries between two such areas, and particularly in relatively sharp areas between the highly charged and lower charged areas, there is an absence of powder deposition resembling very much a light or clear halo surrounding the dark area. Similarly, the heaviest deposits are not necessarily in the areas of highest potential but are, instead, just inside the borders of highly charged areas. This property has in the past been of considerable value in X-ray recording, since it accentuates discontinuities or flaws in relatively uniform test objects. As a result of this, the contrast sensitivity of the xeroradiographic image is substantially increased and, in addition, the exposure latitude is increased, inasmuch as discontinuities or flaws can be detected both in the lighter and the darker areas of the image.

Unfortunately, the property of halo, which is the very property that produces these preferential results, produces also an additional and detrimental result. Very frequently in X-ray examination it is desired in industrial castings to locate casting flaws, or in medical examination to locate and analyze tissue and bone areas when the area of particular interest in the X-ray examination is an area at or near a point of sharp contrast differential. Thus, in medical examination, it may be desired to detect a bone injury at or near a joint or, in industrial examination, it may be desirable to detect flaws which might be

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more prevalent near seams, joints or sharp contour changes in the test object. For example, if a casting is being analyzed by X-ray examination, the purpose of the examination very often is to detect the present or absence of flaws associated with sharp angles in the surfaces. It is exactly this type of flaw that could occur in the halo area of the xeroradiographic plate and which is somewhat more likely to be partially masked by the halo itself.

It is, therefore, an object of the present invention to provide new means, methods and apparatus for xeroradiographic examination wherein one anticipated advantage is increased readability of the X-ray record in areas of sharply varying contrast.

It is another object of the invention to provide new means, methods and apparatus for xeroradiographic examination in which there is enhanced contrast sensitivity with particular reference to contrast sensitivity in areas of sharp contrast gradation.

Additional objects of the invention will in part be obvious and will in part become apparent from the following specification and drawings in which:

Fig. 1 is a perspective view of an illustrative test object.

Fig. 2 is a side cross section of the test object of Fig. 1.

Fig. 3 is a diagrammatic presentation of a xeroradiographic print of the test object of Figs. 1 and 2 produced according to prior art methods.

Fig. 4 is a diagrammatic presentation of a xeroradiographic print produced according to the methods of the present invention.

Fig. 5 is an enlarged fragmentary view of a portion of a xeroradiographic print as illustrated in Fig. 3.

Fig. 6 is an enlarged fragmentary view of a portion of a xeroradiographic print as illustrated in Fig. 4.

Fig. 7 is a diagrammatic illustration of a probable mechanism of electrical operation according to the present invention.

Essentially, the operation of the present invention calls for a dual development procedure in which a xeroradiographic latent image is first developed under conditions enhancing detail presentation in certain areas of the image, and the image is subsequently again developed under different conditions of opposite charge, enhancing detail presentation in the remaining areas of the image. Preferably this is accomplished by successive development steps in one of which development is carried out with a cloud or gas suspension of finely divided particles of one color and electrical polarity followed by a second development step with a cloud or gas suspension of particles of a contrasting color and opposite electrical polarity. As a result of this dual operation, particles of the one color are preferentially deposited or developed in relatively large areas and areas of gradual contrast differential, whereas particles of the contrasting color are preferentially developed or deposited in what are normally the halo areas of a xeroradiographic print. By these successive contrasting development steps there is produced a xeroradiographic print retaining essentially the advantages of enhanced readability produced by the halo characteristic while at the same time substantially overcoming the masking effect of halo with respect to sharp contrast areas.

For the manufacture of developer materials of appropriate colors and triboelectric properties, a suitable dye or pigment may be added to a usable resin carrier or binder, and the colored resin may then be pulverized to form a fine powder, preferably of about 5 micron particle size. Desirably for many purposes it is ultimately useful to fuse or melt the developer to form a permanent image, although for many test purposes a fusible image is not necessary. In the manufacture of a thermoplastic toner or developer, a suitable resin such as a rosin-modified phenol-

formaldehyde resin, an acrylic type resin, a polystyrene resin or the like may be mixed with a dye or coloring material such as malachite green oxalate, Victoria Pure Blue B. O., Methylene Blue Chloride and Phthalocyanine Blue, and pulverized to form the desired powder. Developer compositions that have been found to disperse into a positively charged cloud, and thus accomplish reversal development include, for example, Du Pont Oil Red and a medium high molecular weight polystyrene resin having a ball and ring melting point of 125° C., Quinoline Yellow with the same polystyrene and with polybutyl methacrylate, and Oil Blue ZN with polystyrene and polybutyl methacrylate. Oppositely, or negatively charged developers for direct development include, for example, Victoria Pure Blue B. O. and the same polystyrene resin Methylene Blue Chloride and polystyrene, and Phthalocyanine Blue and a rosin modified phenol formaldehyde resin available under the name Amberol F-71. In addition, other colored powder materials may be selected from existing and available powders, and depending on the polarity of their charge when dispersed into a cloud, may be used for positive or negative deposition.

Example I

A test object was examined by xeroradiography according to the following procedure. The X-ray sensitive recording plate was a flat metal plate having an 80 micron layer of vitreous selenium on its surface and available from The Haloid Company of Rochester, New York. The plate was sensitized by charging its surface uniformly to a potential of about 600 volts and a casting to be examined was placed between the plate and the X-ray source. The casting had a thickness ranging between ¼ inch minimum and 2 inches maximum and exposure to a 100 k.v.p. X-ray source was set at 5 milliamperes for 10 seconds at 30 inches target-object distance. The result of the charging and exposure was a developable xeroradiographic latent image.

The latent image as produced was developed first with a bluish-gray appearing powder such as one containing malachite green oxalate in a polystyrene resin. This material was sprayed into a powder cloud through a steel nozzle and the cloud was thus charged to predominantly negative electrical polarity. The suspension was then presented to the inverted surface of the image plate whereby the particles were deposited predominantly in the relatively more highly charged areas of the xeroradiographic image. Because the image surface was held upside down, gravitational deposition was avoided. The image was then given a second development operation in which it was developed with a reddish colored powder such as a mixture of a polystyrene resin with a dye available from the Du Pont Company of Wilmington, Delaware, under the name Du Pont Oil Red. The red powder was sprayed through a steel nozzle and thus received a positive polarity electric charge so that it deposited substantially in the so-called halo areas of the xeroradiographic image. As thus deposited, the blue-gray powder produced the primary xeroradiographic image and the contrasting red colored powder effectively filled in the halo areas to produce a xeroradiographic print of substantially improved readability. The developed image was examined on the xeroradiographic plate itself and was transferred by pressure contact to a coated paper surface.

Example II

The procedure of Example I was repeated in various combinations with positively charged powders and negatively charged powders as indicated below.

In different procedures the image was first developed with the negatively charged powder followed by subsequent development with the positively charged powder and in reverse operation, first with the positively charged and next with the negatively charged powder. Care was taken to employ contrasting colors for the different development

operations. The developed images were characterized by better presentation of detail in the halo areas. In particular, where the area of primary interest in the examination was in the relatively thinner parts of the casting, development with the positively charged powder was carried out first and development with the negatively charged powder in the subsequent operation. In the event, however, that general examination was desired or in the event that detail was considered primarily important in the thicker areas of the casting, the first development operation was carried out with the negatively charged powder. The powders employed were various of the powders such as illustratively listed hereinbefore.

It is believed that a better understanding of the present invention is possible in conjunction with the figures set forth in the drawings. In Fig. 1 there is illustrated a casting generally designated 10 having a broad or relatively thinner area 11 and thicker areas 12 such as a circumferential ring or the like. Illustrated in the figure is a flaw 13 in the casting extending into both the thinner and thicker areas.

In Fig. 2 is presented a cross section view of the same casting illustrating the comparative differences in thickness.

In Fig. 3 is illustrated diagrammatically a developed image according to prior xeroradiographic techniques in which the xeroradiographic plate is charged to positive polarity and exposed to a test pattern of penetrating radiation such as, for example, a pattern of radiation resulting from the passing of X-rays from an X-ray source through the test object of Figs. 1 and 2 and onto the xeroradiographic plate. Following exposure in this manner the xeroradiographic plate is developed by deposition thereon of negatively charged powder, as in accordance with the first portion of Example I, to yield a xeroradiographic print generally corresponding to the print illustrated in Fig. 3. The print, generally designated 10a, shows a relatively heavier image deposit 12a in the thicker or ring area 12a corresponding to the thicker portion of the casting and a relatively lighter deposit in the inner portion 11a corresponding to the thinner portion of the casting. The crack 13 of the casting is reproduced as a flaw line 13a in the xeroradiographic print. Immediately on the thick side of the boundary between the thick and thin portions of the casting is a heavy halo area 14 of excessive developer deposition and immediately inside the boundary is a light halo area 15 of substantially no developer deposition. The flaw line 13a or other evidence of casting defect is largely masked by the overriding effect of the halo, particularly in the light halo area.

In Fig. 4 is illustrated diagrammatically a xeroradiographic print produced by the complete procedure of Example I. Illustrated in this figure is the thick image 12b corresponding to the thicker portion of the casting and the thin image 11b corresponding to the thinner portion. Between these two areas is the halo area image portion 15b corresponding to the second color development of Example I. In this portion of the halo area, the flaw line 13b is visible, and this fact is contrasted to the comparable portion of the image in Fig. 3.

In Figs. 5 and 6 is illustrated in greater detail the deficiency according to the prior art and the elimination of the deficiency according to the present invention. In Fig. 5 is illustrated an enlarged portion of the print of Fig. 3 showing the outer ring area 12a and the inner area 11a with the halo area 15 between the two larger areas. It is also noted that a very dark image area 14 surrounds the outer ring and is in fact positioned to correspond to the edge of dark areas and thus to correspond to areas of greatest gradation of electric potential in the xeroradiographic latent image. Directly adjacent to the dark area 14 is a corresponding light or halo area such as halo area 15 between the ring and the central area or such as the non-image area immediately outside the image. Within this halo area 15 there is substantially no detail visible in the xeroradiographic print. It is observed with reference

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back to Fig. 3 that the flaw line 13a which is visible through the dark area 14 disappears substantially completely as it passes through the halo area.

In Fig. 6 is illustrated a comparably enlarged portion of the modified xeroradiographic print illustrated in Fig. 4. Here the dark or edge lines 14 are retained and remain in predominately the same deposition color as area 12a. In a preferred example the original deposition to form area 12a was a greenish-gray image powder and the subsequent deposition was a red powder. In the comparable area 12b the composite image was predominately a gray-green with only a faint trace of red. Generally similar in appearance was the inner area 11a of the first color development corresponding to the thin section of the test object. This area largely retained its original or in the preferred embodiment gray-green tone with, however, a somewhat more prominent red under-tone. Between edge line 14 and the inner area 11b corresponding to the original halo area 15 is an area 15b containing a substantial deposit of the second image color. In the preferred embodiment this was a clearly apparent red image area showing full detail of casting structure from the test object. This halo area was almost wholly the second image color, or in the preferred embodiment a red image, and substantially free of the first image color. It extended in gradually increasing density from the rather low print density of the second color in the inner area 11b to a heavy print density in the halo area 15b. At its other edge, it extended substantially up to the dark area 14. There was a very fine line of demarcation between the edge of the red deposit of the halo area and the dark area, but even in this sharp area of demarcation there was a tendency of the second developing color to "spill over" into the boundary area between them so that no image area in this entire zone was entirely free from deposited developer material. Referring back to Fig. 4, it is observed that the flaw line 15b is visible through the original halo area even to the extent of being visible in the boundary area between the filled-in halo and the dark area.

As a result of the present invention, xeroradiography including the methods of the present invention is capable of xeroradiographic analysis for flaw detection with contrast sensitivity at least as fine as 1% contrast sensitivity. Even in halo areas excellent contrast sensitivity is observed.

In Fig. 7 is illustrated one explanation of the operation of the present invention, although it is to be understood that this explanation is presented in illustration of the invention and not in limitation. In Fig. 5 there is shown diagrammatically a xeroradiographic print generally designated 21 comprising a conductive backing member 22 and an X-ray sensitive insulating layer 23 disposed on the surface of the conductive backing. Illustrated in the figure are two thick area images 25 corresponding to the thicker areas of the test object and a thin area image 26 corresponding to the thinner areas of the test object. As illustrated by the plus marks in the figure, the relatively thicker test object areas correspond to a higher potential or more dense electric charge remaining on the plate as the xeroradiographic image, whereas the thinner areas of the test object are represented by a relatively lower charge as illustrated by more widely-spaced plus marks in the drawing. The lines of force associated with the charged image are illustrated as generally emanating from the image surface with, however, substantial distortion of the field of force being caused by fringing at the areas of highest charge. Thus, at the boundary of the highly charged areas, relatively larger proportions of the lines of force associated with the dense charge fringe outwardly and then pass back into the image surface to enter the conductive backing surface. Thus, immediately adjacent to the areas of highest charge there is an effective reverse field of force caused by this fringing of the lines of force of the image. The result is that negatively charged powder particles will be attracted to both the

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highly charged image areas and the moderately charged image areas, but will be actively repelled from the halo area surrounding the highly charged portions. This property is utilized in the halo area development operation by the deposition of positively charged powder particles which are affirmatively attracted to these halo areas. As is apparent, the deposition in the halo areas is an image deposition in that it clearly reflects image characteristics of the charge pattern.

The two-color images prepared according to the present invention are characterized in that they present a greater amount of analytical detail in areas of widest charge differential in the xeroradiographic latent image. In particular, flaws to be detected in areas adjacent to wide contrast ranges are more clearly presented in the resulting xeroradiographic print.

In achieving the results of the present invention, it is particularly important to employ in the successive development steps two development materials of contrasting color as well as of contrasting charge polarity. If, for example, materials of relatively similar color density and hue are employed, the contrast in the halo areas is destroyed and the image becomes muddy in appearance and grossly lacking in detail. Similarly, if the image material in the two development steps is not of contrasting polarity, then there is a failure to fill in the halo areas. Likewise, if attempts are made to use the contrasting powders simultaneously, it has been found that the advantages of the invention are not realized.

As a general guide, the major development is carried out with developer particles of electric charge having opposite polarity to the charge originally applied to the xeroradiographic plate for sensitization. This polarity may be imparted by forming the xeroradiographic developer into a cloud or mist and subsequently charging the cloud or mist to the desired polarity by suitable means such as, for example, by passing the cloud through an area of corona discharge or through an area of radioactive discharge. It has been found, however, that by suitable selection of the powder material and by suitable selection of capillary material, a powder spray may be charged predominantly to a desired polarity by passing it under turbulent conditions through a fine capillary. In this manner, positively charged powder clouds have been formed using a wide variety of powder materials of varying colors. As a general guide, it is usually desirable to employ a relatively neutral color such as a blue, gray, green, or the like which is visible in sharp contrast against a white background, for the primary development operation so that the image on the gross basis is easily visible against the white background. If desired, a white image may be employed and viewed against a dark plate surface without transfer.

The second development operation is carried out using a developer material of contrasting color and, as stated before, a contrasting polarity. In general, this is designed to be readily visible in contrast to the particular powder or developer material chosen for the primary development. This material, similarly, may be empirically selected by experimentation with turbulent passage through a fine capillary to select those materials which charge to opposite polarity. Thus, when the xeroradiographic plate is sensitized to positive polarity, the secondary developer will be selected to be of positive electric charge. If desired, a material of either positive or negative frictional charging may be formed into a cloud and charged to the desired opposite polarity by means of corona discharge or the like. This developing material is of contrasting color, and usually of what is best described as a colorful shade such as red, rose, bright blue, bright green, lavender, or the like, to be clearly contrasting with the other developer.

As a preferred embodiment of the invention, it has been found that development of the secondary or halo area developer may be carried out either in the first

development step or in the second development step, with the understanding that in an image where the secondary development step has been carried out first followed subsequently by the primary development, the image in the halo areas is more definitive. Conversely, if the primary development step is first in sequence, then the image in the thicker casting areas or normal development areas is more definitive.

It is to be understood that the present invention may be employed for X-ray examination or similar examination by penetrating radiation of medical or industrial test objects. Similarly, there may be used any suitable radiation sensitive insulating layers charged to either negative or positive polarity as may be desired. For purposes of illustration, the invention has been described in terms of X-ray examination of industrial castings employing vitreous selenium as the radiation sensitive layer and with positive polarity charging for sensitization. This is in accord with presently preferred techniques, but it is to be understood that the invention is not thus limited in its scope. It is similarly to be understood that many variations in techniques and developer materials may be employed within the general scope and guidance of the present invention.

What is claimed is:

1. In a xeroradiographic inspection method including uniformly charging a photoconductive insulating layer overlying a conductive backing surface, exposing said layer to a pattern of penetrating radiation to form a charge pattern thereon, and developing said surface by depositing thereon finely divided charged powder particles in accordance with the electrostatic field associated with said charge pattern, the improvement comprising again developing said surface, while said powder and charge pattern remain thereon, by depositing thereon in accordance with the electrostatic field associated with said charge pattern particles of another finely divided powder of color different from and charge polarity opposite to that originally used.

2. A method of developing an electrostatic charge pattern on an insulating surface comprising first depositing on said surface, in accordance with the electrostatic field associated with said charge pattern, finely divided particles of a first color and bearing an electrostatic charge of a first polarity, and then depositing on said surface while said charge pattern and said deposited particles remain thereon and in conformity with the electrostatic field associated with said charge pattern finely divided particles of a second color distinguishable from said first color and bearing an electrostatic charge of polarity opposite to said first polarity.

3. A method of developing an electrostatic charge pattern on an insulating surface overlying a conductive back-

ing comprising first depositing on said surface in conformity with the electrostatic field associated with said charge pattern finely divided particles of a first color and bearing an electrostatic charge of a first polarity, and then depositing on said surface, while said charge pattern and said deposited particles remain thereon and in conformity with the electrostatic field associated with said charge pattern, finely divided particles of a second color distinguishable from said first color and bearing an electrostatic charge of polarity opposite to said first polarity, said second color particles depositing primarily in areas of the surface not covered by said first color particles.

4. A method of developing an electrostatic charge pattern on an insulating surface overlying a conductive backing comprising first electrostatically attracting to said surface finely divided particles of a first color and bearing an electrostatic charge of a first polarity and then attracting to said surface while said charge pattern and said first polarity powder remains thereon finely divided particles of a second color distinguishable from said first color and bearing an electrostatic charge of polarity opposite to said first polarity, particles of said first and second colors depositing principally in separate areas.

5. A method of developing an electrostatic charge pattern on an insulating surface overlying a conductive backing comprising first exposing said surface to a gaseous suspension of finely divided powder particles of a first color and bearing an electrostatic charge of a first polarity and then exposing said surface, while said charge pattern and said first polarity powder remain thereon, to a gaseous suspension of finely divided powder particles of a second color distinguishable from said first color and bearing an electrostatic charge of polarity opposite to said first polarity, particles of said second color depositing primarily in areas of the surface not covered by particles of said first color.

6. A method of developing a surface carrying a single polarity charge pattern with a corresponding two-polarity electrostatic field pattern comprising first depositing on areas of said surface having a first field polarity finely divided particles of a first color and of opposite polarity to said first field polarity and then while said charge pattern and said particles remain on said surface, depositing on areas of said surface having a second field polarity finely divided particles of a second color contrasting with said first color and of polarity opposite to said second field polarity.

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