Jan. 14, 1958 A. R. KUNES 2,820,146

INTENSIFYING SCREENS

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Fig. 1

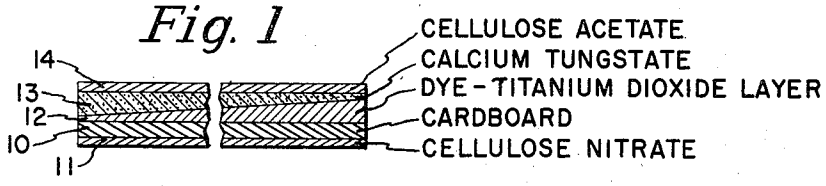


Fig. 2

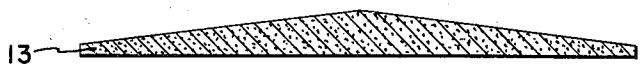


Fig. 3

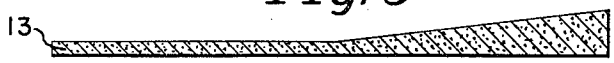


Fig. 4

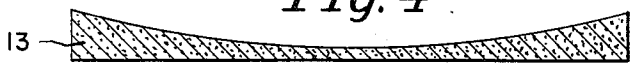
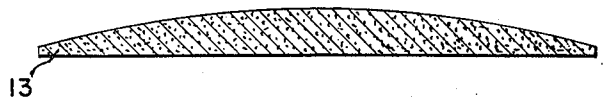


Fig. 5



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INTENSIFYING SCREENS

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8 Claims. (Cl. 250—80)

This invention pertains to X-ray intensifying screens and more particularly to such screens which have variable speeds. Still more particularly it pertains to X-ray screens which have a fluorescent layer of varying thickness. Still more particularly it pertains to such screens which have a coactive layer inversely varying in thickness and containing light-reflective particles in a dyed layer.

In radiological practice a radiograph is made by exposing to X-rays from a subject a sheet of photographic film having a light-sensitive silver halide emulsion layer on each surface of a light-transparent film base, said film being positioned in a suitable light-proof holder of cassette. In order to obtain greater photographic densities in the radiographs, it is customary to have in surface contact with each emulsion layer an X-ray intensifying screen which generally consists of a thin layer of X-ray-excitable phosphors of fine grain size dispersed in a polymeric film-forming binding agent on a sheet support, e. g., cardboard. When X-rays are allowed to traverse the contacting photographic film and screens, the phosphor layers luminesce, emitting light in the visible and near ultraviolet region of the spectrum to which the silver halide in the emulsion layers exhibits its maximum sensitivity. Thus, the resulting photographic silver image densities are increased as much as thirty-fold over those obtained from the action of X-rays alone.

Under conditions of constant energy of X-radiation, the magnitude of radiographic image density is proportional to the amount of absorption of X-rays prior to passing through the assembled film holder or cassette. This absorption is dependent, in turn, on the quantity or thickness of impeding matter. Radiographic pictures are a possibility only because different materials (flesh, bone, metal, etc.) absorb X-rays to a varying degree. Since the light output of the intensifying screens is proportional in part to the intensity of the exciting X-radiation, materials of heterogeneous opacity to X-rays effectively cause corresponding differences in silver image density in the developed and fixed photographic film. These density variations form an image of the complex structure of the object through which X-rays have passed.

It is frequently of practical interest to radiograph extended portions of the human body, e. g., the placenta or, in another case, the spinal cord as viewed from a lateral position, which are so situated that X-rays must penetrate varying thicknesses of tissue before reaching the structure under examination. Considering the latter example, one extremity of the spinal column may underlie several inches of flesh while at some other point the bone may be very near the body surface. Unless special measures are taken, the resulting radiograph will be characterized by an overall gradation of densities and contrasts such that diagnostic interpretation may be rendered difficult.

Various methods of correcting for the X-ray exposure of objects of varying thickness are known. Thus, wedge-type filters have been placed in the path of the X-ray beam before it reaches the cassette. Again, X-ray intensifying

screens have differently, i. e., variably, colored or dyed areas, or variably reflective back supports, or layers of different thicknesses, or variable areas containing two phosphors having different light powers have been proposed, to enable one to produce a more accurate radiograph.

An object of this invetnion is to provide an improved variable speed X-ray intensifying screen. Another object is to provide such a screen which can be used in making better radiographs of the placenta and spinal region of the human body. Yet another object of the invention is to provide such screens which can be used in a simple manner by the ordinary technician. A further object is to provide variable speed X-ray intensifying screens which will fit into the conventional types of X-ray exposure holders and cassettes. A still further object is to provide such screens which can be manufactured in a simple and economical manner. Other objects are to provide variable speed X-ray intensifying screens which are uniform in quality and do not require expensive equipment for their manufacture. Still additional objects will be apparent from the following detailed description of the invention.

The above objects are accomplished by the variable speed X-ray screens of this invention which comprise a sheet support permeable to X-rays bearing a layer of X-ray fluorescent material which varies gradually in thickness along one axis and has the same thickness along a perpendicular coplanar axis and a contiguous coactive sublayer of inversely varying thickness that contains finely divided inert white pigment particles and a dye which absorbs a portion of the light rays emitted by the phosphor upon excitation by X-rays, said pigment and dye being uniformly dispersed through a hard film-forming binding agent. The resulting X-ray intensifying screens may have a clear or light-transparent protective layer on the surface of the fluorescent layer or the former can be uniformly tinted or colored with a dye which absorbe fluorescent rays. This dye absorbs a fraction of the emitting light and decreases the intensity of the emanating radiation. The dye is permeable to the exciting X-rays but is an absorbing material for the fluorescent rays emanating from the fluorescent material (phosphor particles) on excitation by X-rays.

The variable speed X-ray screens of the invention can be made in various ways which in general are the same as those used in making an ordinary X-ray intensifying screen. One practical way comprises first depositing on a smooth casting surface such as polished metal or glass a protective layer composed of a hard film-forming material, preferably a water-resistant material, for instance, a cellulose ether or ester which yields hydrophobic films, e. g., methyl cellulose, ethyl cellulose, cellulose nitrate, cellulose acetate or propionate, cellulose acetate propionate, cellulose acetate butyrate, a synthetic resin or superpolymer, e. g., polymethyl methacrylate, polystyrene, polyvinyl chloride, poly(vinyl chloride co vinyl acetate), polyvinylidene chloride copolymers with isobutylene, styrene, acrylonitrile, vinyl chloride, vinyl acetate, methyl acrylate or itaconic acid, including two of such last mentioned ethylenically unsaturated compounds. These film-forming materials can be applied from solution or dispersion in an organic solvent or water or a mixture of such liquids. Suitable solvents include acetone, dioxane, methylene chloride, 1,1-dichloroethylene, trichloroethylene; ethanol, n-propanol, isopropanol, n-butanol; n-amyl acetate, n-butyl acetate; nitromethane, nitroethane; toluene, xylene; butyl phthalate and diisobutyl ketone. In addition, plasticizers, e. g., dimethyl phthalate, dibutyl sebacate, dioctyl phthalate, dioctyl sebacate, di-2-ethylhexyl adipate, butoxyglycol adipate, glycerol monolaurate, butyl stearate, butyl tartrate, tributyl citrate, ethyl

o-benzoyl benzoate and tricresyl phosphate can be used. When aqueous dispersions are coated, wetting and dispersing agents, e. g., sodium dodecyl sulfate, sodium hexadecyl sulfate, sodium octadecyl sulfate and mixtures thereof; N-cetylbetaine and aluminum stearate are used.

Next there is applied to the set or dried protective layer a viscous dispersion of fluorescent or phosphor particles, e. g., calcium tungstate, zinc sulfide, barium lead sulfate, etc. in a polymeric binding agent which may be a film-forming material as described in the preceding paragraph, and an organic solvent as described above, to form a layer of variable thickness with respect to one axis. This layer can be spread by means of a doctor blade which has its film shaping surface of varying shape. For example, it may gradually increase to form a wedge-shaped or tapered surface, a slightly curved, e. g., parabolic surface, or it may both increase or decrease to form a convex surface or a concave surface, all with respect to one axis and have a surface of uniform thickness along all points of a perpendicular coplanar axis. In the preferred aspect of the invention the doctor blade is adjusted to give a wedge-shaped, regularly tapered profile along one perpendicular axis. This may be accomplished by tilting a straight doctor blade slightly as a coating is applied or spread on the protective layer or by tilting the casting surface. In general, the surface need not vary more than about 0.030 to 0.040 inch in thickness between the thinnest and thickest points, in order to give an adequate difference in the degree of fluorescence and consequent sufficient degree of compensation in the final silver image. Differences in width up to 36 inches or more are practical.

Next, there is applied to the fluorescent layer a viscous dispersion of (*a*) white pigment particles, e. g., titanium dioxide, alumina, magnesium carbonate or diatomaceous earth of average diameter of less than 2 microns, (*b*) a dye which absorbs light in the blue region of the spectrum and (*c*) a hard film-forming material or binding agent in an organic solvent to form a layer which has varying thickness the inverse of the fluorescent layer. The upper surface of this layer preferably is flat or parallel to the protective layer so that the total thickness of the entire X-ray intensifying screen will be uniform. The thickness of the reflective filter layer in general will be the same as the fluorescent layer.

Obviously the dye selected should be soluble in the solvents used to dissolve the above film-forming material, and compatible with components of the dried layer. A further requirement is that, when incorporated in the above dried layer, the dye should show substantial optical absorption of the fluorescent light emitted by the phosphor. Dyes suitable for use include:

Tartrazine (Colour Index No. 640)
Victoria Green WB base (Colour Index No. 657)
Hidaco Malachite Green base (Colour Index No. 657)
Chinoline Yellow D sol. in spirits (C. I. No. 800)
Nubian Resin Black (Colour Index No. 864)

Finally there is applied to the surface of the filter layer a suitable support which may be cardboard, e. g., Bristol board free from or having a water-proof backing, e. g., introcellulose or a sheet of plastic material, e. g., cellulose acetate, polystyrene, polymethyl methacrylate, polyethyl methacrylate and poly(vinyl chloride co vinyl acetate). In the case of the plastic materials, they should contain a filler to provide opacity. Suitable fillers include titanium dioxide, lithopane and magnesium carbonate. The cardboard or plastic sheet is calendered over the fluorescent layer. An adhesive can be used if desired. Alternatively, a plastic sheet can be coated or cast from solution or dispersion and dried. After the support is adherent to the appertaining layer, the composite element is stripped from the casting surface whereby the protective layer is outermost.

Another method of making useful screens is to coat the above layers in reverse order onto the cardboard or plastic support.

In the accompanying drawing which constitutes part of this specification:

Fig. 1 is a cross-sectional view of one type of X-ray intensifying screen having uniformly tapered fluorescent and reflective filter layers;

Fig. 2 is a cross-sectional view of a differently shaped fluorescent layer;

Fig. 3 is a cross-sectional view of a still differently shaped fluorescent layer;

Fig. 4 is a cross-sectional view of a still differently shaped fluorescent layer; and

Fig. 5 is a cross-sectional view of a still differently shaped fluorescent layer.

Referring now to Fig. 1, a cardboard support **10** having a nitrocellulose back coating **11** bears on its front surface a uniformly tapered layer **12** of cellulose acetate containing titanium dioxide particles and a dye, next an inversely tapered layer **13** of cellulose acetate containing calcium tungstate particles and finally a cellulose acetate layer **14**. In Figs. 3, 4 and 5, the fluorescent layer is shown in a position opposite from that shown in Fig. 1.

The invention will be further illustrated but is not intended to be limited by the following examples.

Example I

A flat piece of glass was thoroughly cleaned and dried after which a 5%, by weight, solution of cellulose acetate (about 56% combined acetic acid) in dioxane was applied with a doctor blade to form a thin film. After drying, a suspension of calcium tungstate phosphor in a viscous liquid comprising cellulose nitrate dissolved in n-amyl and n-butyl acetates was cast onto the cellulose acetate layer with the aid of a straight-edge doctor blade 17 inches long disposed at a slight angle from horizontal so that at one end the wet phosphor layer was 0.020 inch and at the other end 0.055 inch thick. The coating was allowed to dry for a short time. The spreading device was readjusted so that the doctor blade was 0.010 inch above the thick end of the dried phosphor layer and 0.030 inch above the thin end. A titanium dioxide suspension of the following composition was then applied with the aid of the doctor blade:

	Grams
Titanium dioxide	16.60
Dye solution (5 grams of tartrazine, Colour Index No. 640, dissolved in 200 ml. 95% ethanol)	0.03
Cellulose nitrate solution	75.00

After partially drying, a piece of cardboard was pressed firmly against the titanium dioxide dye layer and, after setting, the composite screen was stripped from the glass. The speed factors of a pair of such screens varied in a continuous manner from 4.99 to 6.13 when exposed to X-radiation at 140 kvp., 2 ma. (A speed factor of 2 equals the speed of a photographic film screen combination relative to the speed of the film alone.)

Example II

A flat sheet of cardboard was coated with the calcium tungstate-cellulose nitrate mixture used in Example I but with the wet thickness of the layer varying from 0.015 inch to 0.055 inch over a distance of 17 inches. After drying, the straight-edge doctor blade was readjusted to clear the thin end of the coating by 0.030 inch and the thick end by 0.005 inch. A coating of the following solution was then applied with the aid of the doctor blade:

	Grams
Cellulose acetate	6.93
Dye solution (same as in Example I)	5.00
Methyl ethyl ketone	61.50
Dioxane	9.90

The resulting screen had a speed factor variation ranging between 3.86 and 5.19 at points 17 inches removed.

The invention is not limited to the use of the specific phosphors described above, as barium lead sulfate, zinc silicate, phosphate, fluoride or sulfide of the activated or non-activated types can be used in like manner. In the case of zinc sulfide or zinc cadmium sulfide screens, they are useful in fluoroscopy.

Although the variable speed X-ray intensifying screens find greatest use in medical radiography (placentagraphy, spinal radiography and the like), they may also be employed to advantage in other types of radiography or fluoroscopy where wide variations in X-ray absorption occur and interfere with the obtaining of satisfactory radiographic results.

An advantage of the invention is that the screens can be made economically. Another advantage resides in the simplicity of their use in radiography as compared with external wedge-filters and X-ray opaque plastic compositions or putties.

Yet another advantage of the invention is ready reproducibility of results which can be attained by their use. Since the speed range of the variable speed screen is a known entity and can be readily calibrated at any intensity of X-ray exposure, it is possible to reproduce results exactly. Such results cannot be obtained with external filters and putties.

A further advantage resides in the control of radiographic properties. Thus, the variable speed screen can be constructed to fit the needs of any particular case, i. e., the speed range can be varied during manufacture to produce a more faithful radiograph of a particular object field. Also the size of the screen can be varied to coincide with the dimensions of the subject to be radiographed. Still other advantages will be apparent from the above description of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A variable-speed fluorescent screen comprising a support, a reflective-filter layer which has varying thickness in a major part of its dimension along one axis and has a uniform thickness along a coplanar perpendicular axis, a fluorescent layer of inversely varying thickness and a protective layer.

2. A variable-speed fluorescent screen comprising a support bearing in order a reflective-filter layer which has varying thickness in a major part of its dimension along one axis and has a uniform thickness along a coplanar perpendicular axis, a fluorescent layer of inversely varying thickness and a protective layer.

3. A variable-speed fluorescent screen comprising a support bearing in order a reflective-filter layer which has gradually varying thickness in a major part of its dimension along one axis and has a uniform thickness along a coplanar perpendicular axis, a fluorescent layer of inversely varying thickness and a protective layer.

4. A variable-speed X-ray intensifying screen comprising a support bearing in order a reflective-filter layer comprising finely divided inert white pigment particles and a dye uniformly dispersed through a hard film-forming polymeric binding agent, said layer being of uniformly varying thickness in a major part of its dimension along one axis and of uniform thickness in incremental coplanar portions along a perpendicular axis, a complementary fluorescent layer of inversely varying thickness comprising finely divided discrete phosphor particles uniformly distributed throughout a hard film-forming binding agent and a protective layer composed of such a binding agent.

5. A screen as set forth in claim 4 wherein said protective layer contains a dye.

6. A variable-speed X-ray intensifying screen comprising a support bearing in order a tapered reflective-filter layer comprising finely divided inert white pigment particles and a dye uniformly dispersed through a hard film-forming polymeric binding agent, said layer regularly increasing in thickness along one axis and being of uniform thickness in incremental coplanar portions along a perpendicular axis, a complementary fluorescent layer of inversely varying thickness comprising finely divided discrete phosphor particles uniformly distributed throughout a hard film-forming binding agent and a protective layer composed of such a binding agent.

7. A screen as set forth in claim 6 wherein said protective layer contains a dye which absorbs fluorescent rays emanating from the phosphor particles on excitation by X-rays.

8. A screen as set forth in claim 7 wherein said pigment is titanium dioxide and said fluorescent particles are calcium tungstate.

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