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DRAWINGS ATTACHED

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(54) PROJECTION SCREEN

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in any by the following statement:—

The present invention relates to a projection screen and more particularly to a front projection screen i.e. of the reflection type.

In the art of projection screens, many attempts have been made to produce a screen which has a high brightness factor. The most efficient type of known screen is capable of an increase in brightness over a matte screen (a substantially perfect diffuser) by a factor of about two times for a reasonable audience accommodation. Further, the screens of the prior art have the particular disadvantage that, for most efficient use of the screen, projection has to be made in substantial darkness since the image contrast and colour saturation are reduced considerably by use in ambient light.

The brightness of front projection screens has been increased from that of a matte surface by the use of various materials and treatment of the reflecting surface to provide a surface that will concentrate the light within narrower angles. Projection screens having such light concentrating surfaces formed by glass or plastic beads, embossed or scored lenticulations, bubbles, etc. are well known and have been in use over an extended period of time. Attempts have also been made to increase the brightness factor by using one of the aforementioned surfaces in conjunction with a screen having an arcuate surface in at least one direction. However, the above combinations of materials and forms of screen supports have not produced a screen capable of being used with a projector having a low light

output or in high ambient light without loss of contrast or colour saturation.

A primary object of the present invention is to provide a front projection screen which has a greatly increased, useful light reflectivity.

According to the present invention there is provided a projection screen comprising a sheet having one surface formed generally of elongated ridges and depressions which are suitable for reflecting within a specified predetermined viewing area a high concentration of light in the form of a projected image which is unaffected by ambient light on either lateral side of the screen which is outside the viewing area, and a support to which the other surface of the sheet is secured is that only the ridged surface thereof is exposed wherein the elongated ridges and depressions are irregular in width and irregular in elongation but are aligned generally in a common direction and wherein between 1000 and 3000 of the elongated irregular ridges are present per lineal inch when measured in the direction perpendicular to the direction of elongation.

The invention may be obtained by using the dull, relatively unsmooth side of a foil, for example, aluminium foil sheeting, for the reflecting surface of a screen. This material is applied to a preferably arcuate support. The dull relatively unsmooth surface of such foil is obtained by the interaction of the facing surfaces of two sheets of the foil when they are compression rolled and separated. The facing surfaces of the sheets, after separation, are found to have randomly aligned and generally elongated irregularities which take the form of surface deformations that extend generally in a direction perpendicular to the direction of movement of the sheets when being compression rolled. It has also been found that a similar surface having such irregularities can be obtained by a multiple strip compression rolling technique for organic polymers; this technique being disclosed in

U.S. Patent 3,194,863. When a polymeric material is used for a screen reflecting surface, the exposed surface, that is, the irregular surface, can be metalized and has been found to provide substantially the same brilliance and performance as that of metallic foil. It is to be emphasized that the dull side of the screen material is used as the reflecting surface. If the other or shiny surfaces of such sheets are used on an arcuate or curved surface, the effect is the same as that of a concavely curved mirror whose light is directed back to a single focal point, resulting in a most unacceptable viewing screen.

The surface that is obtained by compression rolling at least two sheets or continuous webs of, for example, metal of a thickness from 0.5 to 16.0 mils with smooth rollers under a pressure of 1500—25000 pounds per lineal inch and then separating or peeling the sheets or webs apart, produces a preferred directional reflectance of high efficiency. It has been found that some lenticular action is obtained with pressures as low as 1500 pounds per lineal inch although the quality is poor when compared to surface produce under pressures of 8—9000 pounds per lineal inch. Pressures below 1500 pounds per lineal inch produce unsatisfactory results. Similarly pressures over 25,000 pounds per lineal inch tend to produce an "orange peel" configuration screen surface resulting in inferior reflection. The elongated irregularities are randomly aligned to extend generally in a direction perpendicular to the rolling direction of the foil. Very small element size of the individual irregularities is obtained, i.e., 1,000—3,000 per lineal inch compared to 10—40 per lineal inch which is prevalent in most commercial types of screens. Also under these conditions, a groove depth of from 0.5 to 5.0 microns is obtained; a depth in which the preferred embodiment varies between 1.0 and 1.5 microns. Variations of brightness gain, element size and light distributions can be obtained by varying the rolling pressure within the conditions listed above.

Reference is now made to the accompanying drawings in which like reference numerals designate similar parts and wherein:

Fig. 1 is a perspective view of a curved projection screen embodying the invention;

Fig. 2 is a partial sectional view taken substantially along line 2—2 of Fig. 1;

Fig. 3 is a photomicrograph of the light-reflecting surface of a metallic foil having elongated irregularities according to the invention;

Fig. 4 is a photomicrograph of a vertical section through the metallic foil shown in Fig. 3;

Fig. 5 is a graph showing the angular distribution of reflected light by a screen in accordance with the invention as compared

with one screen material of a commercially available type;

Fig. 6 is a diagrammatic side view showing the vertical spread angle of a flat screen having a reflecting surface in accordance with the invention;

Fig. 7 is a diagrammatic side view showing the vertical spread angle of a curved screen having a reflecting surface in accordance with the invention;

Fig. 8 is a diagrammatic plan view showing the horizontal spread angle of the flat screen shown in Fig. 6;

Fig. 9 is a diagrammatic plan view showing the horizontal spread angle of the curved screen as shown in Fig. 7;

Fig. 10 is an enlarged sectional view of a screen support showing one embodiment of a rib pattern for increasing the spread angles of the screen; and

Fig. 11 is a graphical comparison of the cut-off and the spread angles for a non-ribbed and a ribbed, doubly-curved screen in accordance with the invention.

With reference to Fig. 1, a screen 10 comprises a support member 11 and a metallic foil 12 secured to a surface 13 of the support member for reflecting light projected thereon to an audience. The support member 11 can be made of any material having sufficient rigidity to provide a stable curved surface. The support member 11 can be made of metal, resin bonded glass fibres, polyvinyl chloride, or any one of many other plastics materials, and can be flat, curved in at least one direction or, preferably, doubly curved with a parabolic, spherical or ellipsoidal surface.

The metallic foil 12 is secured to and against the surface 13 (Fig. 2) of support member 11 by an adhesive, or other suitable means with the dull side of the foil exposed for projection use and with the foil oriented on the support such that the direction of compression rolling of the foil becomes the horizontal direction or the direction of preferred reflectance on the finished screen. In other words, the elongated irregularities 14, as seen in Fig. 3, extend in a substantially vertical direction relative to the screen. The radius of the surface 13 can be about 4.5 times the screen width for the projection of either still or motion pictures. The precise shape of the arcuate surface 13 is not critical except for very narrow audience spaces. A different radius can also be chosen for the curvature in each of the horizontal and vertical directions.

With reference to Fig. 5, the luminance ratio, or brightness gain, is defined as the ratio of the luminance of a screen material relative to that of a perfect diffuser; a matte surface Curve 16 represents the horizontal light distribution and Curve 17 represents the vertical distribution for a doubly-curved screen having a reflecting surface in accordance

with the invention. The luminance or brightness gain of our improved screen is seen to be approximately 17 "on axis" for a material having a reflecting surface comprising the irregularities 14, as seen in Fig. 3, and falls off sharply with the increase in spread angle especially in the vertical direction. The average gain is approximately ten within the useful viewing angles and the sharp cutoff with spread angle, together with greatly reduced luminance ratio at the higher viewing angles, are extremely effective for the rejection of ambient light.

Superimposed on the curves for the screen of the invention are curves 18 and 19 which are representative of the horizontal and vertical distribution, respectively, of the luminance of one of the best commercially-available screens of which we are aware, having an average brightness gain of less than two. It can be readily appreciated from this comparison of two such screens that the average brightness of a screen in accordance with the invention for the preferred audience angles is many times that of the best commercially-available screen, and that high levels of ambient light are rejected.

This invention makes use of the fact that the screen brightness is increased for an efficient reflecting material as the angle through which the light is spread decreases. However, the reduced spread angle also reduces the size of usable audience space. A screen having such increased brightness comprises, preferably, a support having a doubly-curved surface on which a foil is secured, such that the dull surface of the foil, having the elongated irregularities, is exposed for reflecting projected images.

With reference to Figs. 6—9, it is shown how an assumed audience can be supplied with light reflected from a flat screen 20 tilted at an angle of 11.6° and a curved screen in accordance with the invention tilted at an angle of 9.3° for motion pictures and at an angle of 10.8° for still pictures, the light being supplied by a still projector 22 that has its lens positioned about 11.5 feet from a 40-inch screen and a movie projector 23 that has its lens positioned about 17.5 feet from a screen of the same size. In each case, the dot-dash lines show the direction of light reflection assuming that the screen surface were 100% specular as for a true mirror. The spread angle is measured relative to this line. By comparing Figs. 6 and 7, it can be seen that with the screen 21 curved in a vertical sense, a spread angle of $\pm 10^\circ$ serves the same purpose of full light coverage as is provided by a spread angle of $\pm 22.7^\circ$ for the flat screen 20. The curved screen 21 will therefore provide the brighter image. In the same Figs. 6 and 7, it will also be noted that the curved screen 21 allows overhead ambient

affording the same degree of protection to the audience from any unwanted light.

Figs. 8 and 9 compare the curved and flat screen configurations in plan view. With the screen 21 curved in a horizontal sense a smaller spread angle is required and therefore a brighter view. In this case a spread angle of $\pm 25^\circ$ for the curved screen supplies the same audience space as the flat screen 20 which has a spread angle of $\pm 38.9^\circ$. The rejection of ambient light is also better for the curved screen 21.

As noted above, the radius of curvature of the screen 21 is disclosed as being approximately 4.5 times the screen width for either still or movie projection. In practice, the radius of curvature is not critical except for very narrow audience spaces. In any special case of audience size, viewing distance and/or projection distance, a screen size and screen curvature can be worked out to utilize the reflected light and reject the ambient light to the best advantage. Ambient light reaching the audience causes reduction of contrast, degradation of colour saturation, glare, etc. By curving the screen and with screen material of properly controlled reflection properties the rejection of ambient light is enhanced because (1) the increased brightness reduces the relative effectiveness of the ambient light, and (2) the reduced spread angles that are permitted by double curving the screen allow ambient light to originate from zones closer to the axis of the projector without such stray light reaching the audience than is permitted by conventional screens. Further, conventional screens not only require greater spread angles which accept greater zones of ambient light, but do not cut off sharply at the required angles, as shown in Fig. 5.

For the spread angles shown in Figs. 6—9, it can be computed from the laws of optics and on the assumption that no light is absorbed by or transmitted through the screen, that the brightness as seen by all members of the audience as compared to a perfect diffuser that appears equally bright throughout the entire spread angle of $\pm 90^\circ$ is as follows: (1) for a flat screen in both horizontal and vertical sense (spread angles of 22.7° and 38.9°), the theoretical relative brightness is 3.5; (2) for a screen curved in the vertical sense and flat in the horizontal sense (10° and 38.9°), the theoretical relative brightness is 7.75; and (3) for a screen curved in both the vertical and horizontal sense (10° and 25°), the theoretical relative brightness is 11.0. Thus, it is seen that for an assumed audience, as shown in Figs. 6—9, the improvement in curving in the vertical sense only is in the ratio of $7.75/3.5=2.2$, and for curving in both directions the improvement ratio is $11.0/3.5=3.1$. Consequently, a theoretically perfect flat screen can only show an improvement of less than a factor of 2 over the best com-

mercially-available screen, whereas a theoretically perfect doubly-curved screen shows an improvement of over a factor of 5. It can also be shown that, for practical screen materials which do not, in general, exhibit equal brightness within the usable spread angles, the image on the screen will always appear of uniform brightness from side to side and from top to bottom if viewed from approximately the focal distance of a double curved screen. This essentially includes all of the audience except those in the extreme front or back. For a flat screen, using practical screen materials, the nonuniformity often results in objectionable dropoff of brightness or a "hot spot" type of view.

For an ideal reflection distribution of the light incident on a screen material, it would be desirable to have a constant luminance ratio which would extend to the desired cut off angles and then drop sharply to zero luminance. For example, a no-loss ideal material for coverage angles having $\pm 10^\circ$ in a vertical sense and $\pm 25^\circ$ in a horizontal sense would have a luminance ratio of 11.0 within these angles and zero beyond these angles. Certain aluminium foil materials which have been considered as being acceptable for projection screens might, for example, have a luminance ratio of 16.0 at 0° and then fall off to approximately 4.0 at the spread of $\pm 8^\circ$ vertical and $\pm 25^\circ$ horizontal. While such materials provide an average ratio of approximately 10.0 and, owing to the double curvature of the screen support do not give rise to "hot spots" or nonuniform illumination of any part of the screen for any one observer, anyone near the side of the audience space may see a darker picture and note poorer contrast and colour purity in the presence of strong ambient lights. The luminance ratio curve for available materials does not drop off as sharply as is desirable at the limiting angles. The light represented in the "tail" sections of the curves (at higher viewer angles) is unused and represents a loss of efficiency, but perhaps even more important is the fact that this unused light allows ambient light from wider angles to be reflected by the screen to some observers. The optimum contrast would be obtained with a luminance ratio curve having a flat top and a sharper cutoff.

It has been determined that a flat top and sharper cutoff of the luminance ratio can be obtained by the use of the previously described foil material combined with a suitable rib pattern on the curved surface of the support. Such a rib pattern is not a true "lenticular pattern" because the rib pattern does not present any curved surfaces to the light incident thereon. A "lenticular pattern" may be used but is not required. Such a rib pattern is shown in Fig. 10. It has been determined that the combination of four planar surfaces, as shown in Fig. 10, provides a luminance

ratio that more nearly approaches the optimum condition. Referring to Fig. 10, the rib pattern comprises vertically extending and continuous grooves or striae 30 each comprising a bottom surface F1 and diverging side surfaces S of a length designated by S1 and S2, the divergence being from top to bottom. The surfaces S make an angle θ with the surface F1. The grooves 30 are spaced so as to provide spaced lands F2. Such a pattern of ribs or grooves 30 can be provided on the double curved support material 13 by forming the surface 13 against a male master and then cementing the aluminium foil 12 to the support with the elongated irregularities extending vertically. The surfaces F1 and F2 are actually vertical strips of the spherical surface 13 rather than planar surfaces. The angle θ is measured relative to the plane tangent to the spherical surface defined by either surfaces F1 or F2 at any point. In practice either surface F1 or F2 may be reduced to zero so long as the correct total spherical area is provided.

The value of P, which is the effective pitch between adjacent grooves, should not be larger than 1/1000 of the screen width in order that the rib pattern is essentially unnoticeable at a normal viewing distance; for example, with a 20" screen, $P=1/50''$ which is equal to .020", and for a 30" screen P would have a maximum dimension of .030".

In Fig. 11 the dotted line curves 30 and 31 show the luminance ratio for various horizontal and vertical spread angles, respectively, for a double curved screen having a reflecting surface in accordance with the invention and with no rib pattern. The full line curves 32 and 33 show the horizontal and vertical spread angles, respectively, when an aluminium foil having a narrower spread angle is used as a reflecting surface on a doubly curved screen support having a rib structure as shown in Fig. 10. It will be noted that the horizontal spread maintains an essentially constant luminance ratio of approximately 16.0 to an angle of $\pm 17^\circ$, after which it falls to about 40% of maximum value at $\pm 25^\circ$ and the luminance ratio exhibits a sharp cut-off at large angles. For different screen sizes and audience spaces, it may be desirable to increase the spread angle, which can be accomplished by changing the shape of the grooves and/or lands comprising the rib pattern.

The brightness factor of a front projection screen is significantly increased by using a material having a surface provided with randomly aligned and generally elongated irregularities which concentrates the light at high efficiency within preferred angles as described above. Such an increase in screen brightness together with the rejection of ambient light permits projection of still and motion pictures under high ambient light conditions which heretofore has been impos-

sible with any type of commercially-available projection screen.

WHAT WE CLAIM IS:—

1. A projection screen comprising a sheet having one surface formed generally of elongated ridges and depressions which are suitable for reflecting within a specified predetermined viewing area a high concentration of light in the form of a projected image which is unaffected by ambient light on either lateral side of the screen which is outside the viewing area, and a support to which the other surface of the sheet is secured so that only the ridged surface thereof is exposed, wherein the elongated ridges and depressions are irregular in width and irregular in elongation but are aligned generally in a common direction and wherein 1000 to 3000 of the elongated irregular ridges are present per lineal inch when measured in the direction perpendicular to the direction of elongation.

2. A projection screen as claimed in Claim 1 wherein the elongated irregular ridges and depressions have a groove depth within the range of 0.5 to 5.0 microns.

3. A projection screen as claimed in Claim 1 or 2 wherein the elongated irregular ridges and depressions have a groove depth of from 1.0 to 1.5 microns.

4. A projection screen as claimed in Claim 1, 2 or 3 wherein the ridge surface is curved concavely about a radius of curvature lying in, in use, a substantially horizontal plane and the elongated irregular ridges and depressions extend generally in a direction perpendicular to the plane.

5. A projection screen as claimed in any preceding claim wherein the ridged surface is curved concavely in at least two directions, a first curvature about a radius of curvature lying in, in use, a substantially horizontal plane and a second curvature about a radius of curvature lying in, in use, a substantially vertical plane and generally parallel to the elongated ridges and depression extending across the screen.

6. A projection screen in accordance with Claim 5 wherein the ridged surface is generally spherical.

7. A projection screen in accordance with

Claim 4, 5 or 6 wherein the or each radius of curvature of the screen surface is 4.5 times the width of said screen.

8. A projection screen in accordance with any preceding claim wherein the sheet is a metallic foil.

9. A projection screen in accordance with Claim 8 wherein the metallic foil is aluminium.

10. A projection screen in accordance with any preceding claim wherein the sheet is mounted on and conforms to the support which is provided with spaced, generally parallel and vertically continuous lands formed by striae having diverging side surfaces.

11. A projection screen in accordance with Claim 10 wherein the pitch of the striae is not greater than 1/1000th of the width of the sheet.

12. A projection screen in accordance with Claim 10 or 11 wherein the striae and the lands formed thereby have a generally trapezoidal cross section.

13. A method of preparing a projection screen as claimed in Claim 1, the method being characterized by compressively rolling in one direction two thin sheets of reflective deformable material in facing relationship with one another under pressure within the range of from 1500 to 25,000 pounds per lineal inch, separating the two thin sheets, the inner surface of each which has the irregular ridges and depressions elongated in a direction perpendicular to the direction of rolling, and mounting at least one of the sheets on a support with only its ridged surface exposed.

14. A method as claimed in Claim 13 characterized by the fact that said sheet is mounted on a concavely curved support with the inner facing surface of the sheet, which defines the aligned elongated irregular ridges and depressions, oriented for subsequent projection use in a direction generally perpendicular to the plane containing the radius of curvature of said mounting support.

15. A projection screen substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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elongated ridges and depressions which are
suitable for reflecting within a specified pre-
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which is unaffected by ambient light on either
lateral side of the screen which is outside the
viewing area, and a support to which the other
surface of the sheet is secured so that only
15 the ridged surface thereof is exposed, wherein
the elongated ridges and depressions are
irregular in width and irregular in elongation
but are aligned generally in a common direc-
tion and wherein 1000 to 3000 of the
20 elongated irregular ridges are present per
lineal inch when measured in the direction
perpendicular to the direction of elongation.

2. A projection screen as claimed in Claim
1 wherein the elongated irregular ridges and
depressions have a groove depth within the
25 range of 0.5 to 5.0 microns.

3. A projection screen as claimed in Claim
1 or 2 wherein the elongated irregular ridges
and depressions have a groove depth of from
1.0 to 1.5 microns.

4. A projection screen as claimed in Claim
1, 2 or 3 wherein the ridge surface is curved
concavely about a radius of curvature lying
in, in use, a substantially horizontal plane and
the elongated irregular ridges and depressions
35 extend generally in a direction perpendicular
to the plane.

5. A projection screen as claimed in any
preceding claim wherein the ridged surface is
curved concavely in at least two directions, a
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lying in, in use, a substantially horizontal plane
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curvature lying in, in use, a substantially
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in one direction two thin sheets of reflective
deformable material in facing relationship with
one another under pressure within the range
of from 1500 to 25,000 pounds per lineal
80 inch, separating the two thin sheets, the inner
surface of each which has the irregular ridges
and depressions elongated in a direction per-
pendicular to the direction of rolling, and
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