United States Patent

Hoffman et al.

[15] **3,703,335**

[45] **Nov. 21, 1972**

[54] **MULTIPLE EXPOSURE IMAGING APPARATUS**

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[22] Filed: **Dec. 22, 1969**

[21] Appl. No.: **887,453**

[52] **U.S. Cl.** **355/51,** 355/4, 355/8, 355/46

[51] **Int. Cl.** **G03b 27/32,** G03g 15/00

[58] **Field of Search**...............355/3, 4, 8, 32, 46–51, 355/54

[56] **References Cited**

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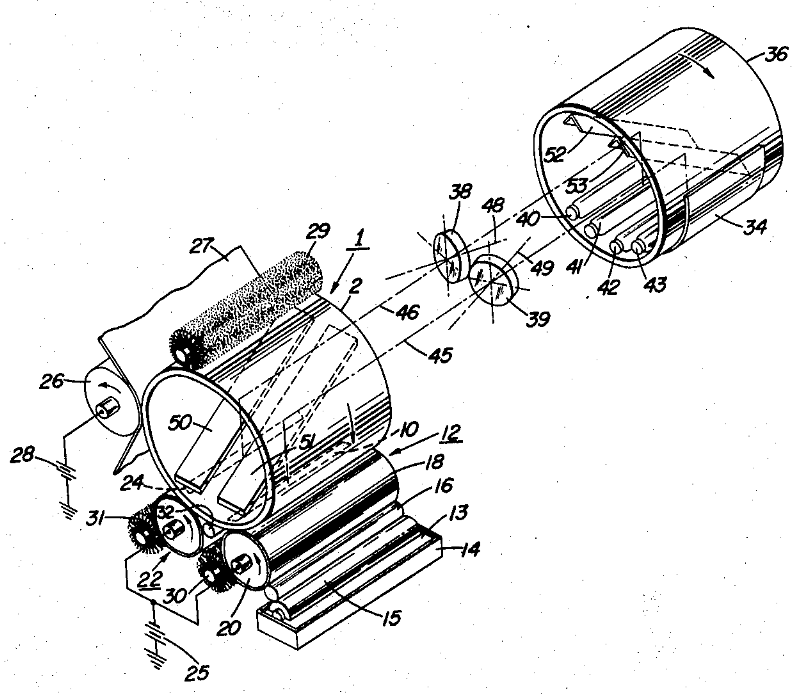
[57] **ABSTRACT**

A machine for automatically making a plurality of superposed exposures optical input from a moving object cylinder carrying a document to a synchronously moving transparent electro-conductive image cylinder for forming the images. Internal to both the cylinders is an optical system for projecting contiguous portions of the object onto a plurality of locations on the image cylinder each in superposed registration. The optical systems are aligned such that a presentation of a point from the object to the image cylinder at one portion of the surface is repeated at the same portion of the surface after the surface has moved from its original position. The optical systems each have a skewed lens and a plane and roof mirror for projecting transferable images without keystone distortion. An embodiment uses the optical re-imaging system for forming photoelectrophoretic images.

20 Claims, 3 Drawing Figures



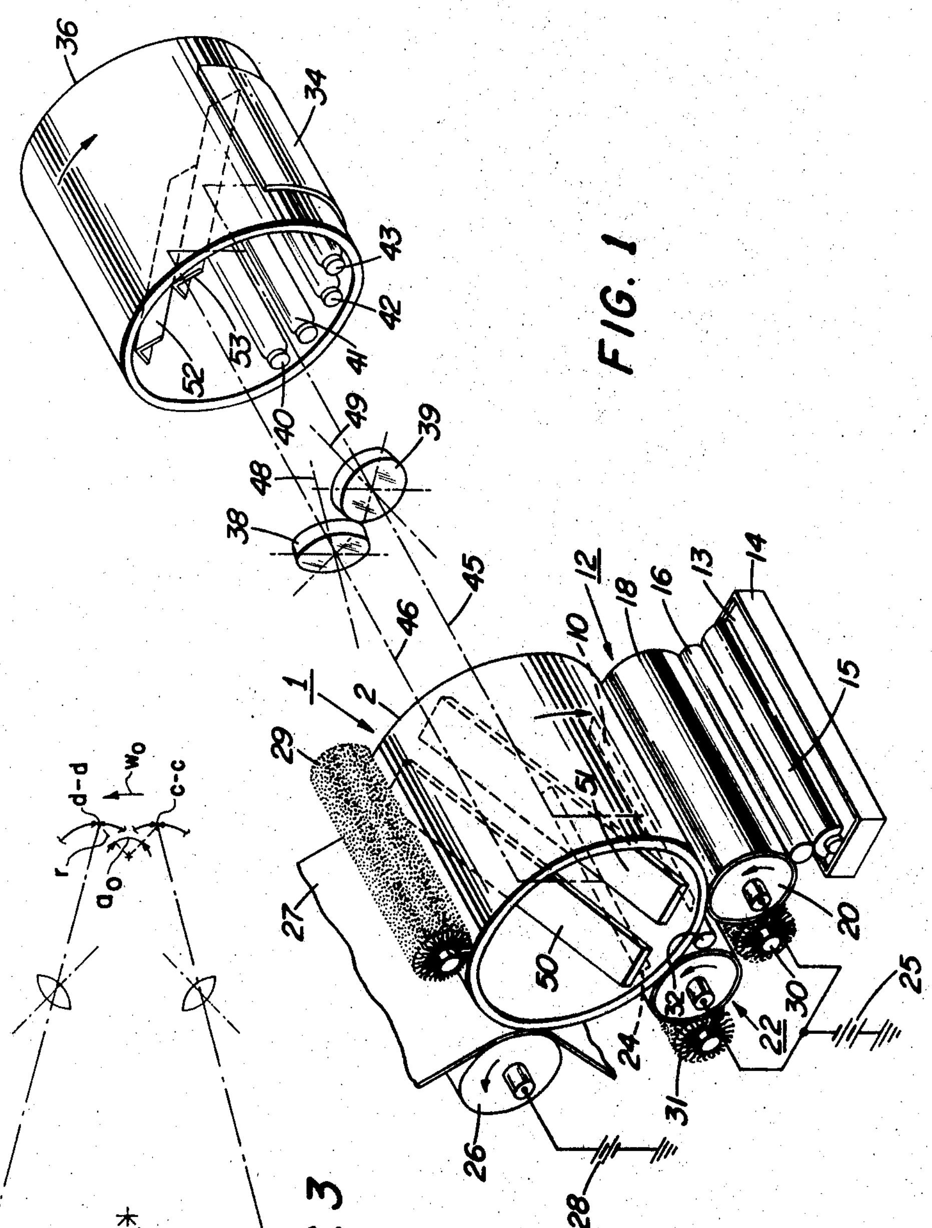


FIG. 1

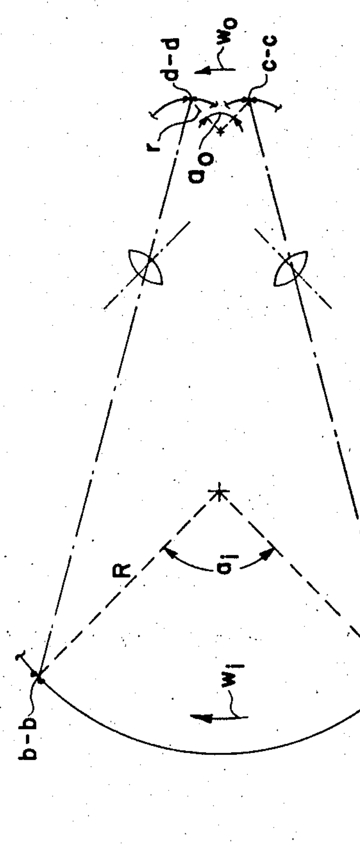


FIG. 3

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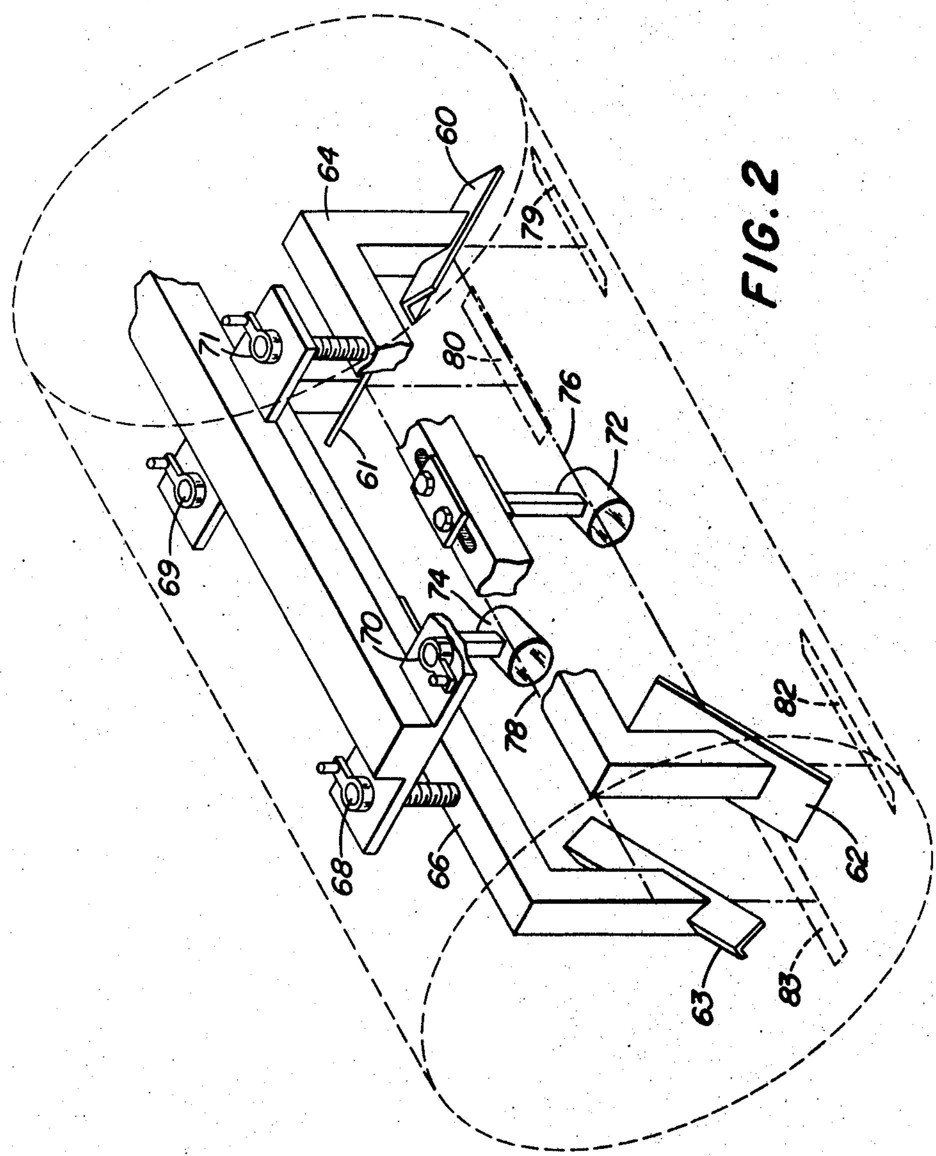

FIG. 2

MULTIPLE EXPOSURE IMAGING APPARATUS

This invention relates to imaging machines and more particularly to machines employing multiple exposure techniques.

Since the new invention of photoelectrophoresis was disclosed for forming black and white or full color images, various machine embodiments have been envisioned to accommodate this imaging technique in an automated machine environment. The basic inventions are described in U.S. Pat. Nos. 3,383,993; 3,384,565 and 3,384,566. They disclose how to produce a visual image at one or both of two electrodes between which photoelectrophoretic particle suspensions are placed. The particles are photosensitive and appear to undergo a net change in charge polarity or a polarity alteration by interaction with one of the electrodes upon exposure to activating electromagnetic radiation. Mixtures of two or more differently colored particles can secure various colors of images. The particles will migrate from one of the electrodes under the influence of an electric field when struck with energy of a wavelength within the spectral response curve of the colored particles.

A continuous imaging machine was disclosed in U.S. Pat. No. 3,427,242 which depicts apparatus for forming continuous images from photoelectrophoretic suspensions by projection of an original utilizing a system for scanning an object and passing the image light rays twice through the transparent surface of a cylindrical electrode.

The practical image formation from the process disclosed above is enhanced in many cases by subjecting the photoelectrophoretic particles to imaging conditions more than once. By re-subjecting the photoelectrophoretic imaging particle suspension to substantially the same image light pattern and an electric field more than once, the final image formed is enhanced by the removal of particles from areas where there was insufficient illumination to previously cause migration of particles from one electrode to another. If a machine such as that disclosed in U.S. Pat. No. 3,427,242 were to attempt to enhance images by re-exposure under imaging conditions a second time using the same projection system, it would require a second revolution of the image forming electrode in that machine. This would reduce the speed and efficiency of the machine by half or more depending on the number of imaging passes determined best for full image enhancement.

Therefore, it is an object of this invention to improve apparatus for automatically producing images. Another object of this invention is to subject photosensitive materials to a plurality of exposures within one cycle of imaging apparatus. Yet another object of this invention is to provide multiple image projection means for forming registered images on moving plates. Still another object is to improve multicolor imaging systems.

These and other objects of this invention are accomplished by using a transparent cylindrical image carrying member that rotates through a path interfacing with a series of components utilized for automated image formation. Photoresponsive material is coated on the outer surface of the transparent cylindrical member and projection of images occurs at a plurality of fixed positions around its periphery. A cylindrical document platen is rotated in a coordinated manner with the cylindrical transparent image carrying member. A coordinated optical system projects contiguous portions of the moving document onto contiguous portions of the moving image carrying member. The projections are matched such that the same portion of the document projected to the image carrying cylindrical member at a first position are matched at subsequent positions in registration so that like portions of the projected object are projected to the same spot on the moving image carrying electrode at each of the image planes of the plurality of the optical projection systems.

The invention herein is described and illustrated in a specific embodiment having specific components listed for carrying out the functions of the apparatus. Nevertheless, the invention need not be thought of as being confined to such a specific showing and should be construed broadly within the scope of the claims. Any and all equivalent structures known to those skilled in the art can be substituted for specific apparatus disclosed as long as the substituted apparatus achieves a similar function. It may be that other processes or apparatus will be invented having similar needs to those fulfilled by the apparatus described and claimed herein and it is the intention herein to describe an invention for use in apparatus other than the embodiment shown.

These and other objects and advantages will become apparent to those skilled in the art after reading the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic isometric representation of an embodiment of a machine for forming photoelectrophoretic images in accordance with the invention herein;

FIG. 2 schematically illustrates a mechanism for varying the magnification of the optical system for image magnification matching, and

FIG. 3 diagramatically shows an unfolded system for re-exposing magnified portions of the object cylinder on an image cylinder.

There are certain terms of art used in conjunction with the photoelectrophoretic imaging process (of FIG. 1) which should be defined. The "injecting electrode" is so named because it is thought to inject electrical charges into activated photosensitive particles during imaging. The term "photosensitive" for the purpose of this disclosure refers to the property of a particle which, once attracted to the injecting electrode, will alter its polarity and migrate away from the electrode under the influence of an applied electric field when exposed to activating electromagnetic radiation. The term "suspension" may be defined as a system having solid particles dispersed in a solid, liquid or gas. Nevertheless, the suspension used in the disclosure herein is of the general type having a solid suspended in a liquid carrier. The term "imaging electrode" is used to describe that electrode which interacts with the injecting electrode through the suspension and which once contacted by activated photosensitive particles will not inject sufficient charge into them to cause them to migrate from the imaging electrode surface. The imaging electrode is covered with a dielectric surface composed of a material having a volume resistivity preferably in the order of 10^7 or greater ohm–cm and a conductive core member which is preferably a resilient material such as electrically conductive rubber used to give flexibility to the imaging electrode.

For photoelectrophoretic imaging to occur it is thought that these steps, not necessarily listed in the sequence that they occur, take place: (1) migration of the particles toward the injecting electrode due to the influence of an electric field, (2) the generation of charge carriers within the particles when struck by activating radiation within their spectral response curve; (3) particle deposition on or near the injecting electrode surface; (4) phenomena associated with the forming of an electrical junction between the particles and the injecting electrode; (5) particle charge exchange with the injecting electrode; (6) electrophoretic migration toward the imaging electrode; (7) particle deposition on the imaging electrode. This leaves an optically positive image on the contacted surface of the injecting electrode.

The schematic representation of FIG. 1 shows a photoelectrophoretic imaging apparatus having an injecting electrode 1 with a coating 2 of transparent electrically conductive material such as tin oxide on the outside surface of a transparent glass member. Such a combination is commercially available under the name of NESA glass from Pittsburgh Plate Glass Company of Pittsburgh, Pa. However, other electrically conductive coatings over transparent substrates are suitable for use herein. At a first imaging area 10 an imaging electrode 12 interfaces with the outer surface of the injecting electrode 1. The imaging electrode carries imaging suspension 13 from the suspension supply housing 14 via a suspension application system having a metering roll 15 and an applicator roll 16. The imaging suspension is applied to the surface of the injecting electrode between the injecting electrode 1 and the imaging electrode 12 at the first imaging area 10.

The imaging electrode 12 has a high dielectric surface 18 overcoated on a conductive flexible inner core 20 which is preferably a resilient material of conductive rubber or the like. A second imaging electrode 22 interfaces with the outer surface of the injecting electrode 2 at a second imaging area 24. Both of the imaging electrodes are connected to the negative terminal of an electrical source 25. The injecting electrode 1 is shown schematically connected to ground so that a field exists between the two imaging electrodes on the one hand and the injecting electrode on the other as is required for the photoelectrophoretic imaging process. In actual practice the electrodes may be coupled to separate sources and even energized to different potentials. The second imaging electrode 22 has a fluid sprayer 32 operatively associated with it to spray carrier material onto the surface. This aids in selectively removing particles of the suspension from the outer surface of the injecting electrode under imaging conditions provided by the optical system and the electrical source. It has been found that the addition of material similar to the liquid carrier of the imaging suspension aids in the migration of particles of the suspension away from the injecting electrode in the second imaging area 24.

Interfacing with the outer surface 2 of the injecting electrode 1 downstream or further along the path of movement of the injecting electrode is the transfer roller 26 and transfer support sheet 27. The transfer roller is electrically connected to a source 28 for causing an opposite polarity to the two imaging electrodes 20 and 22 with their electrical source. It is the function of the transfer electrode to electrophoretically transfer the imaging suspension from the surface 2 of the injecting electrode 1 to a support material which is used as the final image support media. A cleaning brush 29 is placed in contact with the outer surface of the injecting electrode 1 to remove residual suspension remaining on the injecting electrode after transfer has been completed. Similarly, cleaning brushes 30 and 31 contact the imaging electrodes 12 and 22 respectively to clean their surfaces after they interface with the injecting electrode.

The integrated dual optical system shown herein presents superposed imagewise electromagnetic radiation at each of the plurality of imaging areas denoted by the numerals 10 and 24. The image is of contiguous portions of the document 34 placed on the document drum 36 at the object plane of the plurality of the lenses 38 and 39. Radiation energy or illumination is supplied by light sources 40–43. The two reference lines 45 and 46 shown in FIG. 1 represent the principal ray from the object plane to the image plane of the optical system. It should be noted that the document 34 is maintained on a surface of the object drum 36 which passes through the object plane of each of the two lenses 38 and 39. The outer surface 2 of the injecting electrode 1 moves through the image plane of the two lenses at the imaging areas 10 and 24, respectively. The principal rays 45 and 46 shown are not the optical axes of each of the lenses. The optical axes in fact are shown by the reference lines 48 and 49.

Within the dual optical system are equal sets of mirrors including plane mirrors 50 and 51 and roof mirrors 52 and 53 shown in the respective optical paths of the two lenses 38 and 39.

Although only two optical systems are shown it is possible for three or more to be coordinated in the manner of this invention to permit multiple imaging passes with a single revolution of the injecting electrode past a plurality of imaging electrodes equal to the number of coordinated optical systems. The optical systems function to present multiple exposures of the document from various places of the object drum to various pre-selected places of the injecting electrode so that the same portions of the document are projected at each of the various pre-positions on the injecting electrode.

FIG. 2 shows an alternative placement of the optical components to achieve the same results as the optical system of FIG. 1 permitting parallel placement of the lenses. Also shown is a schematic representation of means for varying the distances of the various components from each other and from the object and image planes. The apparatus illustrated enables changing the total conjugate length of the system. The front or rear conjugate between the object and lens and the lens and image plane is also changeable. The mirrors 60–63 are mounted on two fixed frames 64 and 66. They are rigidly locked so that the optical relationship between mirrors 60 and 62 on frames 64, and mirrors 61 and 63 on frame 66 is fixed. The distances between the mirrors and the focal planes of the system may be varied by any means such as the four sets of hanging jacks 68-71 shown. The combination of jacks enables changing the total conjugate length between the object and image planes and a tilting or correction for tilting of the optical system between the object and image planes. This adjustment provides proper focusing of the object light rays onto the image planes. The lenses in the system are movably maintained on the rigid frames by what is shown schematically to be a lockable slide combination. A precision lens bench adjustment is accomplished by removable tools and the lenses are locked after the adjustment. In this way each of the lenses **72** and **74** are movable along the principal rays **76** and **78**, respectively, to vary the magnification of the object at the image plane.

The reason that these adjustments are built into the system is that the mechanical and optical tolerances of manufacture are generally not adequate to ensure proper registration of the image from the second optical system with that previously projected from the first optical system. By pre-setting the distances of the object scanning areas **79** and **80** with the imaging areas **82** and **83** and nominally setting the conjugates and focal length of the multiple imaging optical apparatus to be equal, one can use mechanisms, shown schematically here, to finally adjust for undesirable deviations in the optical system.

Another point to be noted in this figure that is different from FIG. **1** is the orientation of the lenses. In FIG. **1**, the lenses were positioned non-parallel with each other as well as with the principal ray. The benefit of the second system is that closer physical positioning of the optical systems is achievable. The reason the lenses can be positioned parallel with each other in FIG. **2** is that the roof and plane mirrors of one of the systems is reversed in their positions from the roof and plane mirrors of the system adjacent to it. While both plane mirrors are on the image side of the lens in FIG. **1**, only one of the plane mirrors and one of the roof mirrors are on the image side of the lenses in FIG. **2**.

The lenses are offset at some angle relative to the principal rays shown in the accompanying figures in order to provide an orthogonal imaging arrangement. Keystoning occurs when the object plane, image plane, and the plane of the lens are not parallel. The distortion causes an elongation or non-parallelism of parallel object lines. If the systems shown in FIGS. **1** or **2** were unfolded, it would be noted that the image planes represented for example in FIG. **2** by the numerals **82** and **83** are parallel to their respective object planes, namely **79** and **80** and the nodal planes of the lenses **72** and **74**. However, if the lenses were perpendicular instead of skewed to the principal axes **76** and **78**, a severe keystoning problem would occur. Further, the projection of the aerial images would not be tangent to the imaging planes **82** and **83**. If the width of the imaging slits were small, however, the images would be in focus at the image cylinder. Nevertheless, this focused image at each of the image planes would be expanding transversely across the image area. The movement of any point of the image relative to the moving injecting electrode would cause a blur and a distortion as the system scans. Further, in this system it would result in severe lack of registration and resolution causing a blurred final image. To eliminate this undesirable distortion, the lenses are tilted relative to the principal ray so that the plane passed perpendicularly through the lens axis is parallel to the object plane and image plane thus being orthogonal as mentioned above. That is to say it is parallel in the optical sense.

One of the unique features of this three mirrored multiple imaging system is the ability to take two alike curved surfaces as an object and image plane and by moving them in synchronous motion produce an image of the object. The image is optically suitable for transfer to become a right reading final image on a sheet of support material. The object drum and the image drum can be one continuous transparent cylinder if the magnification of the system is set for 1 to 1 or two separate cylinders as shown in FIG. **1**. If two cylinders are used and 1 to 1 magnification is desired, they are of the same diameter and are mechanically locked to be rotated at the same surface velocity making a practical multiple scanning system.

For magnifications different from 1 to 1, the image cylinder radius is equal to the product of the object cylinder radius and the optical magnification. Angular velocity and the angle between imaging stations are equal on both cylinders. Consider the following mathematical definitions and equations:

M = magnification of the image to the object
t_o = time for the object cylinder to rotate through an angle a_o (see FIG. 3)
t_i = time for the image cylinder to rotate through an angle a_i (see FIG. 3)
R = radius of the image cylinder
r = radius of the object cylinder
w_i = angular velocity of the image cylinder
w_o = angular velocity of the object cylinder

1. $t_o = t_i$; necessary for registration in the direction of scan
2. $a_o = a_i$; necessary to keep the object and image planes optically parallel.

The image cylinder velocity $V_i = Rw_i$

3. $Rw_i = Mr\ w_o$; (Necessary for equality of flowing aerial image velocity and moving imaging cylinder velocity)
4. from (1) $a_i/w_i = a_o/w_o$ or $w_o/w_i = a_o/a_i = 1$
5. substituting (3) into (4)

$$R/rM = a_o/a_i = 1 \text{ or } R/r = M$$

Therefore, in a multiple slit scan system the angular velocities of the object and image cylinders are equal for all magnifications and the radii of the cylinders are in the proportions of the magnification.

For magnifications other than 1 to 1, the chord lengths, or the distance between the object slits and the distance between the image slits are different. These relationships can be seen and better understood by reference to FIG. **3**. The object drum is represented as two drums because of the optical relationship represented in an optically unfolded system. The radius r is shown for the drum and its angular velocity w_o is repeated on each representation even though there is only one cylinder and one velocity. The dashed line between the object slits and the image slits indicate the spacing relation of the slits to the lenses and to each other. The mirrors of the system would be displaced laterally depending on their location along the optical path. Their orientation would not change, only their lateral position as would be seen in a plan view of the system.

Depending on the size allowed for the imaging processor, a multiple of any desired number of optical systems within reason, can be accommodated within the system for multiple reinforced imaging of an object.

The optical system can be arranged externally to the cylinders and can be aligned for radial projection thus eliminating the need for turning the lenses as shown in FIGS. 1 and 2. Radial projections are possible internally if the cylinders are sufficiently large to accommodate the optical devices.

In a 1 to 1 magnification system the object and image cylinders are rotating at the same surface velocity through the fixed object and image planes of the multiple optical systems. Because it is preferable to have close registration of each of the projected images, it is necessary to set the precise placement of each optical system relative to the others. Because of the aforementioned conditions the matching of images to produce close registration from the flowing object is achieved by measuring the distances between the various object positions being projected and project them at nearly precisely the same distances along the imaging cylinder. For a magnified system as shown in FIG. 3, the precise distance relationship is as important as for a 1 to 1 system. In FIG. 3 the angles a_o and a_t are the same and the lens nodal planes are parallel to the object and image planes. The conjugate positions of the lenses are in the ratio of the radii R and r.

For this to be achieved the mirrors must be prealigned. Hence, a rigid mirror alignment device such as shown in FIG. 2 is helpful. In order to have acceptable registration, there must be a precise magnification matching of the various optical systems. This is one of the reasons that the lenses are preferred to be movable along the optical path for changing magnification. Another requirement for a good optical system is that the focused image be projected tangentially to the imaging cylinder at the imaging slits. For this reason, a total conjugate variation is beneficial. Again, this is one of the functions of the apparatus shown in FIG. 2, and the combination of lens positioning and total conjugate variation adjustment and in obtaining a precisely registered focused output. To make an optimum resolution multiple optical imaging system, the system should have equal velocity flowing images and image planes. The optical systems should be focused and precisely aligned relative to each other with little or no distortion from keystoning. Image magnification of each should match the others.

While this invention has been described with reference to the structures disclosed herein and while certain theories have been expressed, it is not confined to the details set forth; and this application is intended to cover such modifications or changes as may come within the purposes of the improvements and scope of the following claims.

What is claimed is:

1. Apparatus for imaging including
a single object data support means;
means to move the object data support means for supporting a document;
multiple optical means each having an object position on the object data support means;
image receiving cylinder means;
an image position corresponding to each of the object positions on the cylinder means;
means to rotate the cylinder means;
lens means determining an optical path between an object position and corresponding image position;
reflecting means along the optical path;
to align the multiple optical means for sequentially projecting portions from the object positions in superposed relationship to the corresponding imaging positions.

2. The apparatus of claim 1 wherein the multiple optical means are internal to the cylinder means.

3. The apparatus of claim 2 wherein said cylinder means is transparent.

4. The apparatus of claim 1 including means to illuminate the optical object data support means at each of the object positions.

5. The apparatus of claim 1 wherein the roof reflecting member and the plane reflecting member are located on opposite sides of the lens means.

6. The apparatus of claim 5 wherein the roof reflecting member in one of the multiple optical means is on the same side of the lens means as is the plane reflecting member of the optical means adjacent thereto.

7. The apparatus of claim 6 wherein the lens means of the multiple optical means are parallel with each other.

8. The apparatus of claim 1 wherein the lens means are skewed relative to the principal ray of the optical means.

9. The apparatus of claim 1 including means to move the lens means along the optical path.

10. The apparatus of claim 1 including means to move the lens means and reflecting means relative to the object position.

11. The apparatus of claim 1 wherein said reflecting means includes a plane reflecting member and a roof reflecting member.

12. Apparatus for imaging including
cylindrical object data support means;
means to move the object data support means;
multiple optical means each having an object position on the object data support means;
image receiving cylinder means;
an image position corresponding to each of the object positions on the cylinder means;
to rotate the cylinder means;
lens means determining an optical path between an object position and corresponding image position;
reflecting means along the optical path;
means to align the multiple optical means for sequentially projecting portions from the object positions in superposed relationship to the corresponding imaging positions.

13. The apparatus of claim 12 wherein the cylindrical object data support means for maintaining multiple object positions and the cylinder means for maintaining multiple image positions are cylinders being of approximately equal diameter and rotatable at approximately the same surface velocity.

14. The apparatus of claim 13 wherein said cylindrical object data support means and the cylinder means for maintaining multiple image positions are related in size such that the radius of the cylinder means approximately equals the product of the object data support cylinder and the optical magnification of the optical

means, both cylinders being rotatable at the same angular velocity.

15. The apparatus of claim **14** wherein the angular separation between object positions on the object data support cylinder are equal to the angular separation of the corresponding imaging positions.

16. Apparatus for imaging including
object data support means;
means to move the object data support means;
multiple optical means each having an object position on the object data support means;
image receiving cylinder means;
an image position corresponding to each of the object positions on the cylinder means;
means to rotate the cylinder means;
lens means determining an optical path between an object position and corresponding image position;
reflecting means along the optical path;
means to align the multiple optical means for sequentially projecting portions from the object positions in superposed relationship to the corresponding imaging positions;
multiple imaging electrodes interfacing with the cylinder means at the multiple image positions;
means to couple the electrodes and the cylinder means to electrical source means; and,
means to supply photoelectrophoretic particles between a first imaging electrode and the cylinder means.

17. The apparatus of claim **16** including means to transfer particles from the cylinder means; means to couple said means to transfer to electrical source means of a polarity different from the imaging electrodes.

18. Apparatus for imaging including
1. single object data support means for supporting a document having sequential areas of which are to be sequentially scanned and having spaced areas, spaced in the scanning direction, which are to be scanned concurrently;
2. image receiving cylinder means;
3. a first lens means located along a first optical path which extends between said object data support means and said cylinder means;
4. a second lens means located along a second optical path which extends between said object data support means and said cylinder means, said first optical path and said second optical path being spaced from each other in the scanning direction at said object data support means, at said cylinder means and at said first and second lens means and
5. means to cause relative movement in the scanning direction
   a. between a document at said object data support means and the ends of the optical paths thereadjacent whereby sequential areas of the document are scanned by one of said lens means and thereafter the same sequential areas of the document are scanned by the other of said lens means and
   b. between said cylinder means and the ends of the optical paths thereadjacent whereby images may be projected from said object data support means to said cylinder means along the optical paths in superposed relationship.

19. The apparatus as set forth in claim **18** and further including image reflecting means along both optical paths.

20. Apparatus for imaging including
1. single object data support means for supporting a document having sequential areas of which are to be sequentially scanned and having spaced areas, spaced in the scanning direction, which are to be scanned concurrently;
2. image receiving cylinder means;
3. a first lens means located along a first optical path which extends between said object data support means and said cylinder means;
4. a second lens means located along a second optical path which extends between said object data support means and said cylinder means, said first optical path and said second optical path being spaced from each other in the scanning direction along their entire lengths;
5. means to cause relative movement in the scanning direction
   a. between a document at said object data support means and the ends of the optical paths thereadjacent whereby sequential areas of the document are scanned by one of said lens means and thereafter the same sequential areas of the document are scanned by the other of said lens means and
   b. between said cylinder means and the ends of the optical paths thereadjacent whereby images may be projected from said object data support means to said cylinder means along the optical paths in superposed relationship and
   c. reflecting means along each optical path including a roof mirror on one side of the lens means and a mirror on the other side of the lens means.

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