United States Patent

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[15] **3,685,897**

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[54] **PHOTOELECTROPHORETIC APPARATUS USING PYRAMID GEARS**

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[52] **U.S. Cl.** **355/3,** 355/53, 355/86, 355/95, 95/37

[51] **Int. Cl.**.....**G03b 5/00**

[58] **Field of Search** 355/3, 53, 86, 95; 95/37

[56] **References Cited**

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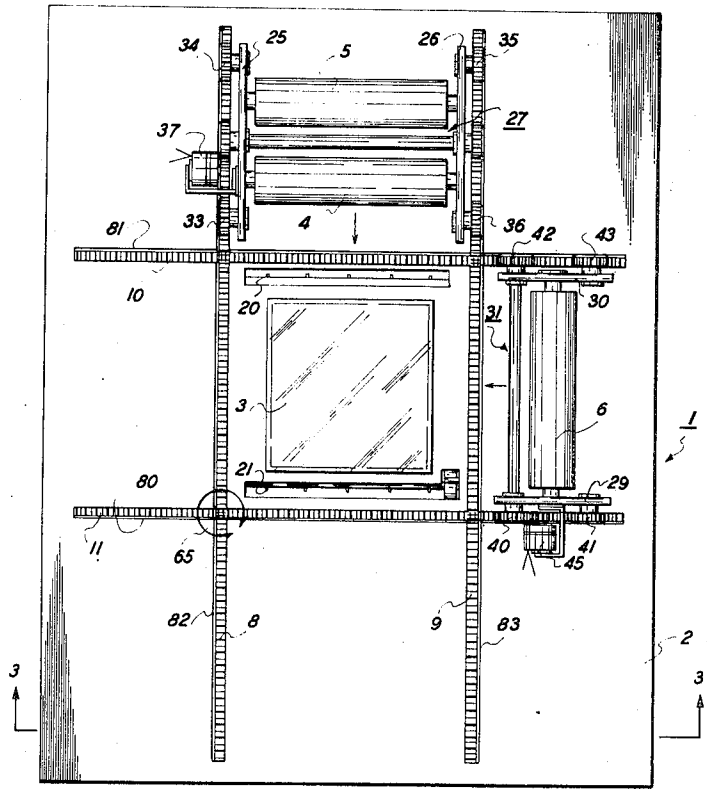
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[57] **ABSTRACT**

A photoelectrophoretic machine employs a flat transparent plate electrode on which images are made from a photoelectrophoretic ink exposed to electromagnetic radiation projected to the ink through the transparent plate and subjected to electric fields established between the plate and roller electrodes supported for travel over the plate. The rollers are journeled in first and second carriages that travel over the plate along different paths. The carriages are supported on pinion gears mated with rack gears on the four sides of the plate and intersecting one another. Pyramid gears are used at the intersections to enable the pinion gears on one rack to cross over an intersecting rack.

8 Claims, 6 Drawing Figures



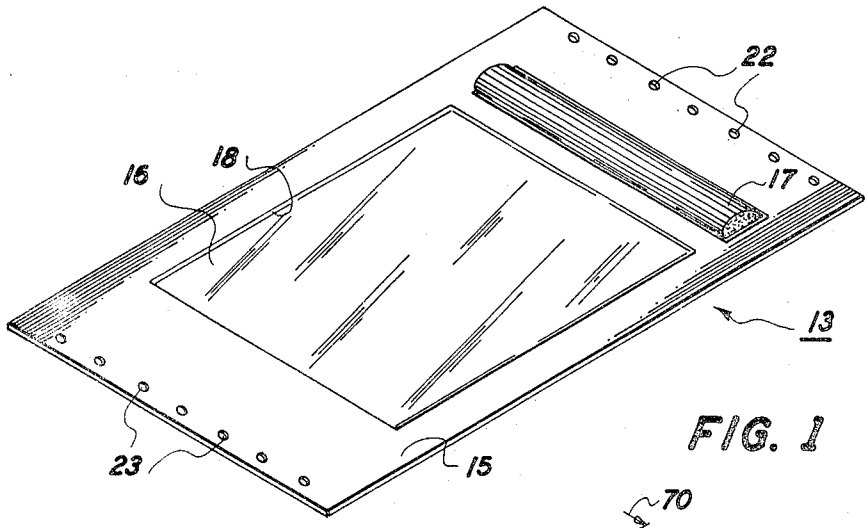


FIG. 1

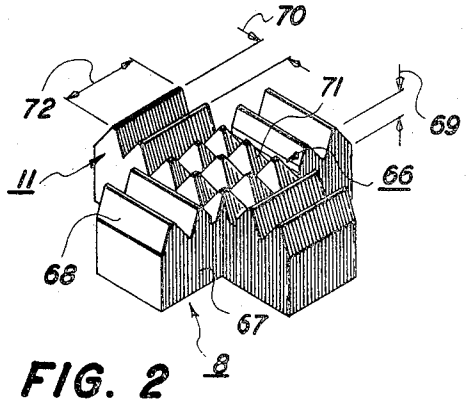


FIG. 2

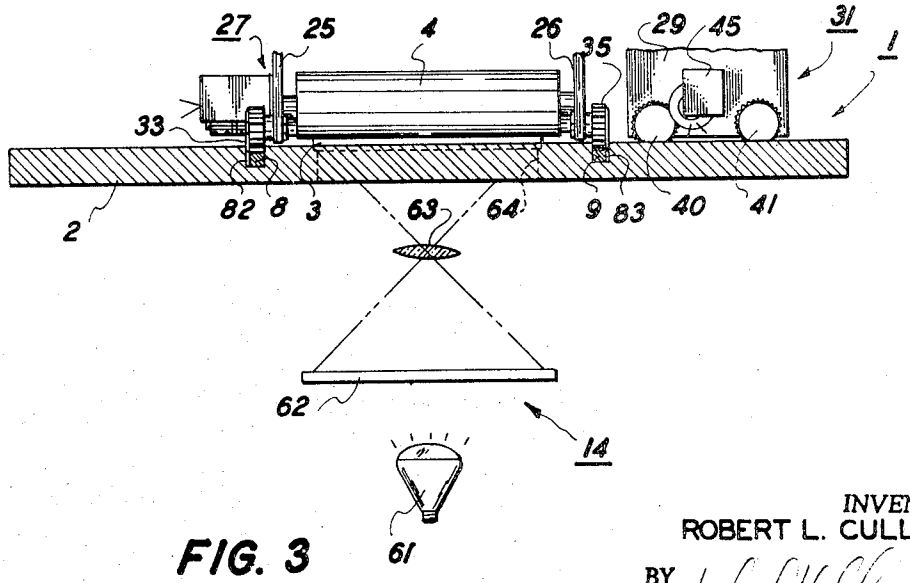


FIG. 3

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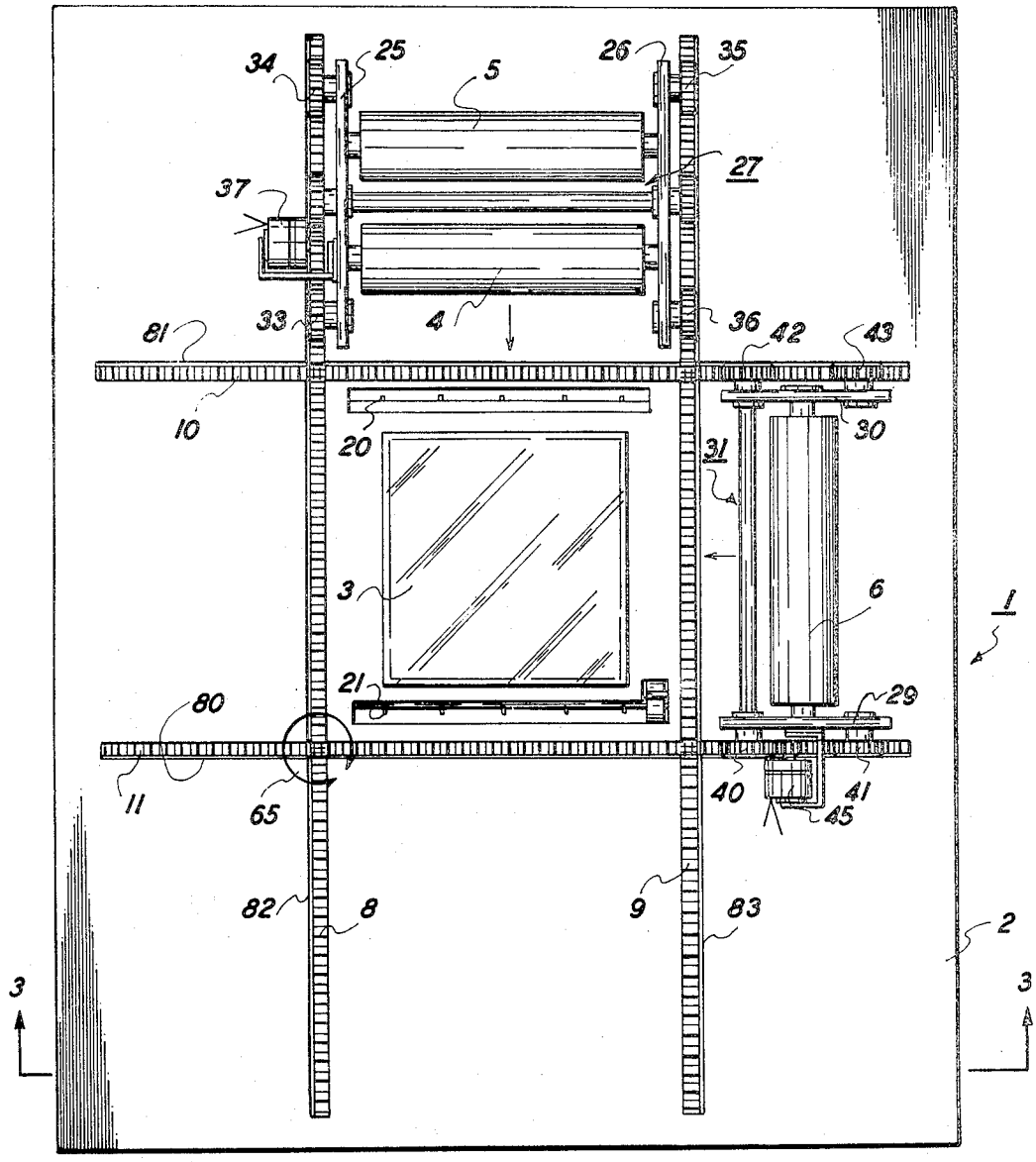


FIG. 4

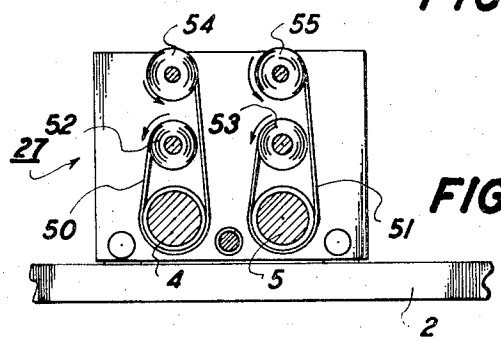


FIG. 5

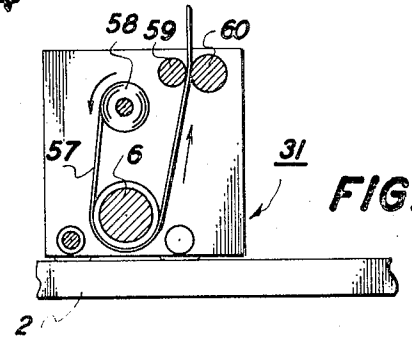


FIG. 6

PHOTOELECTROPHORETIC APPARATUS USING PYRAMID GEARS

BACKGROUND OF THE INVENTION

This invention relates to imaging systems and in particular to novel method and apparatus for the photoelectrophoretic imaging process. Even more specifically, this invention relates to photoelectrophoretic machines.

In the photoelectrophoretic imaging process, an image is formed from an imaging suspension or ink by subjecting the ink to an electric field and exposing it to activating electromagnetic radiation, e.g., light in the visible spectrum. The imaging suspension is composed of light sensitive particles suspended within an insulating liquid carrier. The particles are believed to bear a net electrical charge while in suspension. Conventionally, the ink is placed between injecting and blocking electrodes used to establish the electric field and is exposed to a light image through one of the electrodes which is at least partially transparent. According to one theory, particles attracted to the injecting electrode by the electric field exchange charge with the injecting electrode when exposed to light and migrate under the influence of the field through the liquid carrier to the blocking electrode. As a result of the migration, positive and negative images are formed on the two electrodes. The blocking electrode is covered with a dielectric material to minimize charge exchange and thereby prevent the particles from oscillating back and forth between the two electrodes.

The photoelectrophoretic imaging process is either monochromatic or polychromatic depending upon whether the light sensitive particles within the liquid carrier are responsive to the same or different portion of the light spectrum. A full color polychromatic system is obtained, for example, by using cyan, magenta and yellow colored particles which are responsive to red, green and blue light respectively. An extensive and detailed description of the photoelectrophoretic process is found in U. S. Pat. Nos. 3,384,565 and 3,384,484 to Tulagin and Carreira, No. 3,383,993 to Yeh and No. 3,384,566 to Clark.

Conventionally, photoelectrophoretic imaging apparatus have included multiple roller electrodes that travel one after the other across a flat plate electrode or alternately the plate is moved in a straight path over first, second, third and even more rollers. The first roller may be for electrophoretically applying an ink to the plate, the second for applying an electric field during first exposure, the third to apply an electric field during a second exposure and the fourth for transferring an image formed over the plate electrode. Additional rollers may be for cleaning the surface of the plate after transfer. In the present photoelectrophoretic machine, at least one roller travels over a path that intersects the path followed by the other rollers. This operation requires a drive mechanism that permits one roller to pass over the path traveled by the other rollers.

Accordingly, it is an object of this invention to design a simple and efficient drive mechanism that permits one member to cross the path traveled by another member.

More specifically, it is an object of the present invention to devise means for enabling two roller electrodes in a photoelectrophoretic machine to pass over the same area of a stationary plate electrode at different angles relative to the plate.

Yet another object of the invention is to devise means for enabling a pinion gear to travel along a first rack gear and cross over an intersection with another rack gear.

Still another object is to devise means for machining a section of a rack gear such that it permits travel of a first pinion gear along it yet allows a second pinion gear traveling on another rack gear to cross over it.

The above and other objects of this invention are accomplished by using a pyramid gear at the intersection of two rack gears in a photoelectrophoretic machine. The pyramid gear has teeth shaped to permit pinion gears to run across it in more than one direction. The pyramid gear permits rack gears to be placed in the same plane in a tic-tac-toe configuration wherein two vertical racks intersect two horizontal racks defining a center box and four three-sided figures. Roller electrodes are journeled in two carriages that are supported above the horizontal and vertical racks, respectively, by pinion gears. A transparent plate electrode is positioned in the center box on which images are formed with photoelectrophoretic ink subjected to radiation projected through the transparent plate and electric fields established between the rollers and the plate. The tic-tac-toe arrangement of the rack gears, which are the tracks for the carriages, permits electric fields between the rollers and the plate to be swept over the ink on the plate in different directions to obtain an averaging effect. In addition, the tic-tac-toe arrangement allows the length of the machine to be shortened by the size of a roller. Furthermore, the track-carriage configuration for a roller drive mechanism permits the carriages and its rollers to be interchanged or replaced because they are held to the racks primarily by their own weight. The result is a highly simplified mechanical arrangement for the photoelectrophoretic process.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the film sheet employed in the present apparatus.

FIG. 2 is a perspective view of a pyramid rack gear used at an intersection between rack gears to permit one set of rollers to travel across the path traveled by other rollers.

FIG. 3 is a partial side elevation view of the present photoelectrophoretic machine.

FIG. 4 is a plan elevation view of the present machine with the web handling mechanisms removed.

FIG. 5 is a side sectional view of first web handling mechanisms for a set of two rollers used in the present machine.

FIG. 6 is a side sectional view of a second web handling mechanism used in the present machine.

DESCRIPTION OF THE EMBODIMENTS

FIG. 4 illustrates most of the components of the present machine 1. Machine 1 includes the frame 2, the transparent flat plate 3, first and second imaging rollers 4 and 5 and transfer roller 6. The imaging rollers are supported for travel over plate 3 by means including the imaging rack gears 8 and 9. The transfer rollers are supported for travel over substantially the same area of plate 3 by means including the transfer rack gears 10

and 11. In the specific embodiment shown in the drawings the path followed by the rollers 4 and 5 intersects the path followed by roller 6 at an angle of about 90°. This angle of intersection may be varied to suit the needs of different apparatus. The 90° angle is particularly advantageous because it allows the length of the machine to be shortened significantly; namely, by an amount proportional to the size of a roller. Furthermore, the process is enhanced because the electric fields applied between the rollers and plate are averaged.

Images or copies are formed with machine 1 by spreading a photoelectrophoretic ink over an image forming area of film sheet 13 (FIG. 1) that rests on plate 3. Conventionally, plate 3 is electrically grounded and the three rollers 4, 5 and 6 have high voltages coupled to them. An image is projected to the ink on a film sheet by the exposure means 14 (FIG. 3). The electric field established between the first imaging roller and plate and the activating electromagnetic radiation, e.g., light in and near the visible spectrum, cause migration of ink particles that result in the formation of a negative image on roller 4 (or a web wrapped around it) and a positive image on the film sheet.

Alternately, the electric field applied between roller 4 and the plate 3 may be used to electrophoretically deposit the particles in the ink onto the film sheet while no radiation is being projected. The electric field between roller 5 and plate 3 is used along with the exposure to create the images. If the images are formed with the first roller as described, the second roller 5 is used to subject the ink image on the film sheet to a second exposure and electric field. This second exposure to light and application of field improves the quality of polychromatic images.

The transfer roller 6 has a voltage polarity that establishes an electric field between it and plate 3 opposite in direction to that used to form the image on the film sheet. This field attracts the ink pigments on the film sheet to the roller (or a web wrapped around it) thereby removing or transferring the ink image from the film sheet. The electric field and the mechanical movement of the roller 6 over the plate at the 90° intersection angle tends to offset or average out variations in the resultant transferred image due to variations in the electric field and the mechanical contact between roller and plate. The averaging can be used in forming the image also. In this case, the functions of the second imaging roller 5 and transfer roller 6 are interchanged. The first imaging roller 4 travels over the plate 3 with light on and voltages applied to form an ink image. Next the roller 6 passes over the plate at the 90° intersecting angle to expose the ink image and subject it to field a second time. Next the roller 5 is passed over the plate to transfer the ink image to it (or a web wrapped around it). A suitable mechanism is used to elevate roller 5 out of contact with a film sheet 13 on plate 3 when roller 4 is passed over the plate and to elevate roller 4 out of contact with a film sheet when roller 5 is passed over the plate.

The photoelectrophoretic ink used to form the ink images is introduced into the process by means of the film sheet 13. The film sheet includes a paper body 15, transparent image forming section 16 and the rupturable pod 17. The pod contains the ink and releases it when crushed by one of the rollers. The pod is a paper or plastic sack glued or otherwise appropriately attached to the body 15. The transparent section is glued or otherwise appropriately attached to body 14 over the cut-out 18 on the side opposite the pod. It is transparent to the radiation projected by the exposure means 14. The transparent section or sheet is on the side opposite the pod to provide a border for the image on the film sheet when it is not transferred. The transparent sheet 16 is separated from the body 6 to provide the final product. Because the ink is spread over the transparent sheet only in areas of cut-out 18 in body 14, the border is inherently provided for the ink image.

The film sheet is stretched out over the flat plate 3 (with pod 17 facing upward) by means of the hooks 20 and 21 on either side of plate 3. The film sheet has holes 22 and 23 on opposite ends that mate with the hooks. An appropriate spring bias mechanism is coupled to one set of hooks to tightly stretch the film sheet across the plate.

The rollers 4, 5 and 6 are composed of conductive metal cores having conductive rubber wrapped around their peripheries to give good compliance between the rollers and plate 3. The rollers include means for coupling to appropriate voltage sources. Rollers 4 and 5 are journeled for rotation in the side walls 25 and 26 of carriage 27 while transfer roller 6 is journeled for rotation in side walls 29 and 30 of carriage 31. The carriages are movably coupled to the rack gears 8–11 for travel along paths defined by the rack gears.

Carriage 27 is coupled to rack gears 8 and 9 by the pinion gears 33–36. The pinion gears are mated with the rack gears and are journeled in the side walls of the carriage to support the carriage. The electric motor 37 is mounted on the carriage and is drivingly coupled by appropriate means such as pulleys and belt to pinion gears 33 and 34 for rotating them and propelling the carriage along racks 8 and 9 over the plate 3. The motor is reversible to allow travel in two directions over the plate.

Carriage 31 is coupled to rack gears 10 and 11 by the pinion gears 40–43. The pinion gears are mated with the rack gears and are journeled for rotation in the side walls of the carriage 31 to support the carriage. The electric motor 45 is mounted on the carriage and is drivingly coupled by appropriate means such as pulleys and belt to pinion gears 40 and 41 for rotating them and propelling the carriage along racks 10 and 11 over the plate 3. The motor 45 is reversible to allow travel in two directions.

The rollers 4, 5 and 6 are mounted in their respective carriages at elevations relative to plate 3 to cause them to be forced by the weight of the carriage against the plate (or a web and film sheet between the rollers and plate). The bearing blocks in which the rollers are journeled may be coupled to lift or elevator mechanisms that raise or lower the elevation of the rollers relative to the plate. The elevators are used to hold a roller out of contact with the plate during the carriage's travel or to urge a roller under pressure against plate 3.

The webs 50 and 51 shown in FIG. 5 are wrapped around rollers 4 and 5 to serve as the blocking layer during first and second imaging (exposure to light and application of field) of ink on the film sheet. The webs include electrically insulating materials and they are

wound between the supply reels **52** and **53** and the take-up reels **54** and **55**, respectively. The supply reels have drag brakes coupled to them to maintain tension in the webs. The take-up reels are drivingly coupled by appropriate means to the motor **37**. The web is pulled around the free rolling rollers **4** and **5** at a velocity substantially equal to the translational speed of the carriage but in the opposite direction. The webs are used to eliminate the need to clean the periphery of the rollers.

The transfer web **57** shown in FIG. **5** is wrapped around the transfer roller **6** and is the final support for the ink image formed on the film sheet. The web **57** is wound onto the supply reel **58** and pulled therefrom by the friction drive mechanism including opposed rollers **59** and **60**. Roller **59** is drivingly coupled to motor **45** to pull the webs **57** around free rolling roller **6** at a velocity about equal and opposite to the translational velocity of the carriage.

The webs **50**, **51** and **57** are wrapped around their respective rollers **4**, **5** and **6**. The reels supporting the webs are coupled to the side plates of the carriages **27** and **31** respectively. The reels are fixedly supported relative to the rollers to move with them. The reels are mounted on the same side of the rollers to obtain the wrap around and are mounted generally vertically above the rollers to take up the least possible room. They are positioned on the opposite side of the rollers from plate **3** so that they are drawn tightly against the rollers and so that if any skid or slip between the webs and plate occurs the webs are unlikely to be pulled off the roller. The drive mechanism pulling the webs around the rollers do so at a velocity equal and opposite to that of the carriage to prevent skidding or slipping. The resultant web handling mechanisms are compact, efficient and independent of one another so that it is unlikely that one web will get in the way of another, i.e., adversely interfere with the feeding or threading of each other.

The exposure means **14** shown in FIG. **3** includes the lamp **61**, transparency **62**, and lens **63**. This mechanism can be replaced by reflection exposure means for projecting an image of an opaque original. The plate **3** and the film sheet are transparent to the electromagnetic radiation generated by lamp **4** to allow the radiation to act on ink on the film sheet between a roller and plate. The frame **2** includes the cut-out **64** to permit the radiation image pattern to reach the plate **3**.

The plate **3** includes transparent plate glass having a transparent conductive layer such as tin oxide on its side facing the rollers. The conductive layer is normally coupled to electrical ground.

The carriages **27** and **31** are able to intersect each other's path because of the pyramid gears placed at the intersections of the rack gears. The isolated, perspective view of intersection **65** (FIG. **4**) is representative of the three other intersections. Sections of rack gears **8** and **11** are cut-out at the vicinity of the intersection of gears **8** and **11** and the removed pieces are replaced by the pyramid gear **66**. Each rack gear includes a body **67** having the triangular cross-section, linear teeth **68**. The teeth of each rack gear are identified by their height **69**, length **72** and their peak-to-peak spacing **70**, or pitch. The height and pitch of the different gears are designed to mate with like teeth on the pinion gears **33–36** and **40–43**. The height and pitch are generally the same for all gears in this embodiment but may vary one from the other in different embodiments.

The pyramid gear is formed from a member having teeth similar in height and pitch to one of the rack gears. The teeth of this member are then cut by a tool at the desired intersection angle as if the teeth of a height and pitch of the other rack gear were being made. For the present case wherein the rack gears intersect at about 90° and the height, length and pitch of the teeth on each rack gear are generally identical, the resultant machined part resembles the pyramid gear **66** shown in FIG. **2**. Gear **66** is characterized by the square based pyramid shaped teeth **71**. The pyramids **71** have a height and peak-to-peak separation (in the directions of the two racks) that permit the pinion gears **33** and **34** to run over it on rack **8** and pinion gears **40** and **41** to run over it on rack **11**. The height of the pyramid teeth is at least about the height of the taller teeth of the pinion gears.

The pyramid teeth **71** of gear **66** are arranged at right angles in rows and columns. The rows and columns are parallel to the length of the teeth on the two intersecting rack gears. The number of teeth in each row and column is proportional to the length **72** of the teeth on the intersecting rack gears. Because the length of the teeth of the rack gears shown are the same, there are equal numbers of teeth in the rows and columns. In the specific case of gear **66**, three pyramid teeth are substantially equal to the length of the teeth on an intersecting rack gear. Preferably, the length of the teeth on the two rack gears are even multiples of the peak-to-peak spacing of the teeth on the two rack gears. For example, rack gear **8** may have a teeth length equal to four pyramid teeth while rack gear **11** has teeth three pyramid teeth long as illustrated.

The rack gears are seated in the grooves **80–82** cut into the frame **2**. The grooves are laid out in a tic-tac-toe pattern with horizontal grooves **80** and **81** intersecting the vertical grooves **82** and **83** (as seen in the plan view of FIG. **4**). The rectangular cross-section of the grooves (FIG. **3**) is designed to mate with the cross-sectional shape of the rack gears. The pyramid gears are positioned at the intersections of the grooves meaning that each rack gear is separated into three pieces. For clarity of presentation the rack gears are discussed as continuous members because the pyramid gears in fact enable them to function as if they are continuous.

Other modifications to the above described invention will be apparent to those skilled in the art and are intended to be incorporated herein.

What is claimed is:

1. In a photoelectrophoretic imaging system of the type wherein images are formed from photoelectrophoretic ink spread over a transparent plate by exposing the ink to activating electromagnetic radiation and subjecting the ink to electric fields established between the plate and roller electrodes supported to travel over the plate, the improvement comprising drive apparatus for said rollers including

a first carriage in which at least one of said roller electrodes is journeled for rotation, said carriage being supported for travel over said plate by pinion gears mated with first and second rack gears positioned on opposite sides of said plate,

a second carriage in which at least one of said roller electrodes is journeled for rotation, said carriage being supported for travel over sad plate by pinion gears mated with third and forth rack gears positioned on opposite sides of said plate and intersecting said first and second rack gears, and

pyramid gears at the intersections of said rack gears for permitting the pinion gears on a rack gear to cross over an intersecting rack gear.

2. The apparatus of claim 1 wherein said rack gears intersect at angles of about 90°.

3. The apparatus of claim 1 wherein said pyramid gear includes teeth similar to the teeth of one intersecting rack gear having portions of said teeth removed to mate with the pinion gear traveling on the intersecting rack gear.

4. The apparatus of claim 1 wherein said pyramid gear comprises pyramid teeth having square bases, heights equal to the height of the taller teeth of the intersecting rack gears and peak-to-peak spacing about equal to the peak-to-peak spacing of the teeth on the intersecting rack gears.

5. The apparatus of claim 1 wherein said rack gears include teeth having triangular cross-sections, a finite height and a finite length and a constant peak-to-peak spacing.

6. The apparatus of claim 5 wherein the height, length and peak-to-peak spacing of the teeth on all the rack gears are substantially the same.

7. The apparatus of claim 5 wherein said pyramid gears include pyramid shaped teeth aligned parallel to the teeth of the intersecting racks in numbers proportional to the length of the teeth on the intersecting racks.

8. The apparatus of claim 7 wherein the peak-to-peak spacing of the intersecting rack gears are substantially equal.

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