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United States Patent

Wernikoff et al.

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[45] **Apr. 11, 1972**

[54] ELECTRO-MECHANICAL SHUTTER ARRAY

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[22] Filed: **Apr. 1, 1970**

[21] Appl. No.: **24,715**

[52] **U.S. Cl.** ..... **95/53 E,** 350/270

[51] **Int. Cl.** **G03b 9/08**

[58] **Field of Search** ..... 350/270; 95/53 R, 53 E; 355/40, 72

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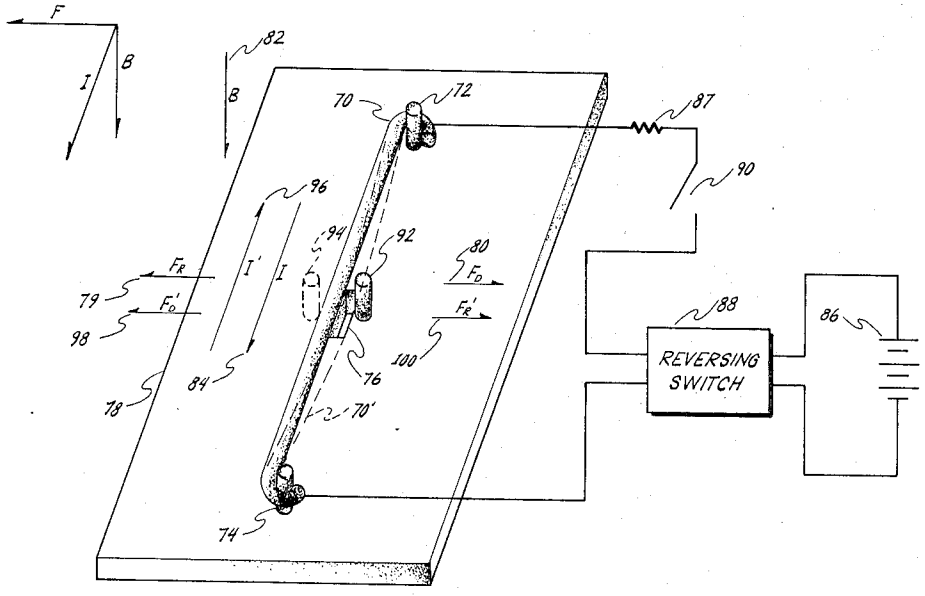
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Attorney—Russell L. Root and Joseph Iandiorio

[57] **ABSTRACT**

An electromagnetically driven mechanical shutter including a conductor element in a magnetic field for enabling the element to be moved laterally between first and second predetermined positions as a function of the current through the element, means, associated with the element, for introducing current therethrough and stop means associated with the element and adjacent one or both of the positions for positively establishing one or both of the positions of the element. A plurality of such shutters may be included in a linear array which may be combined with a source of radiation to be gated by the shutters to expose a photosensitive material to be printed upon and further combined with photosensitive means for sensing radiation from an object carrying information to be read.

13 Claims, 15 Drawing Figures



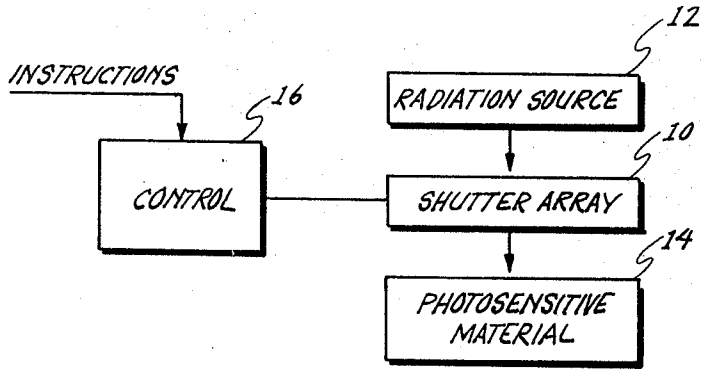


FIG. 1

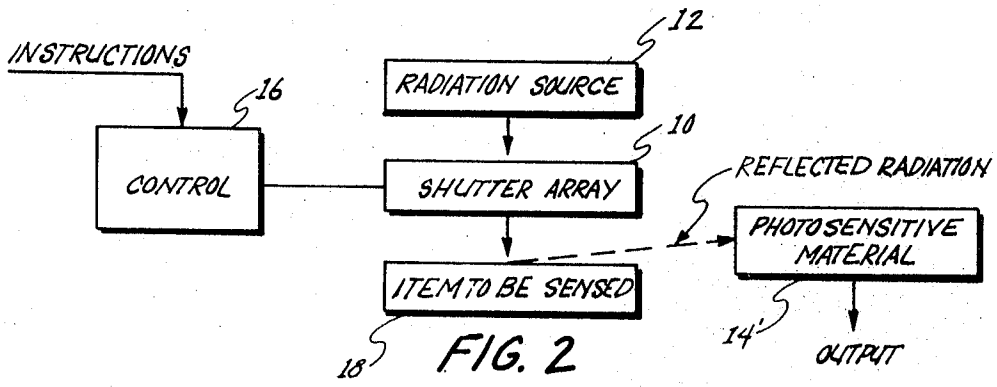


FIG. 2

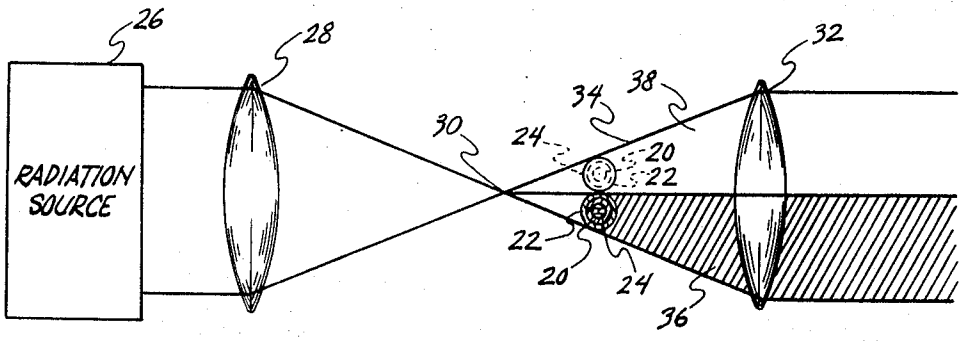


FIG. 4

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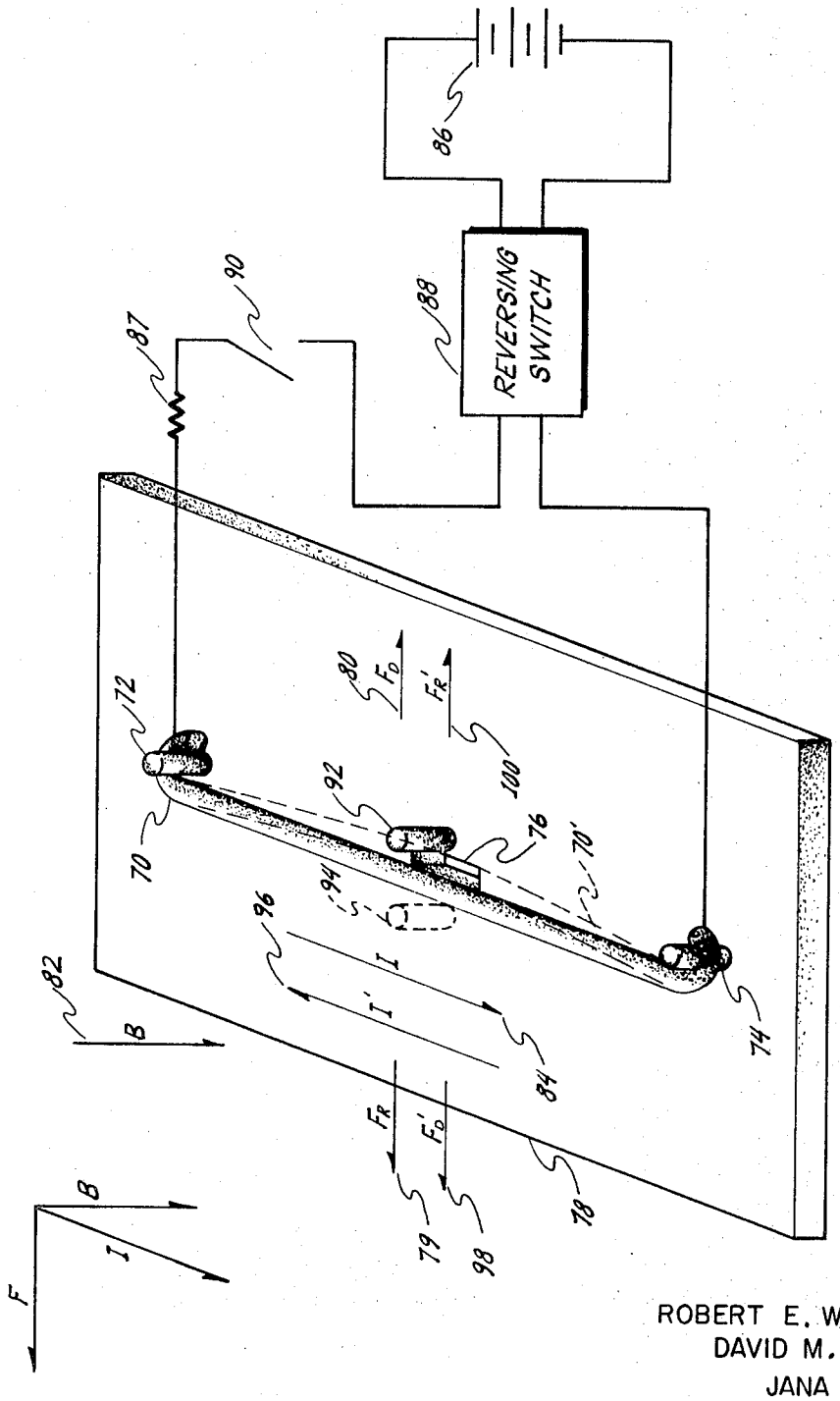


FIG. 3

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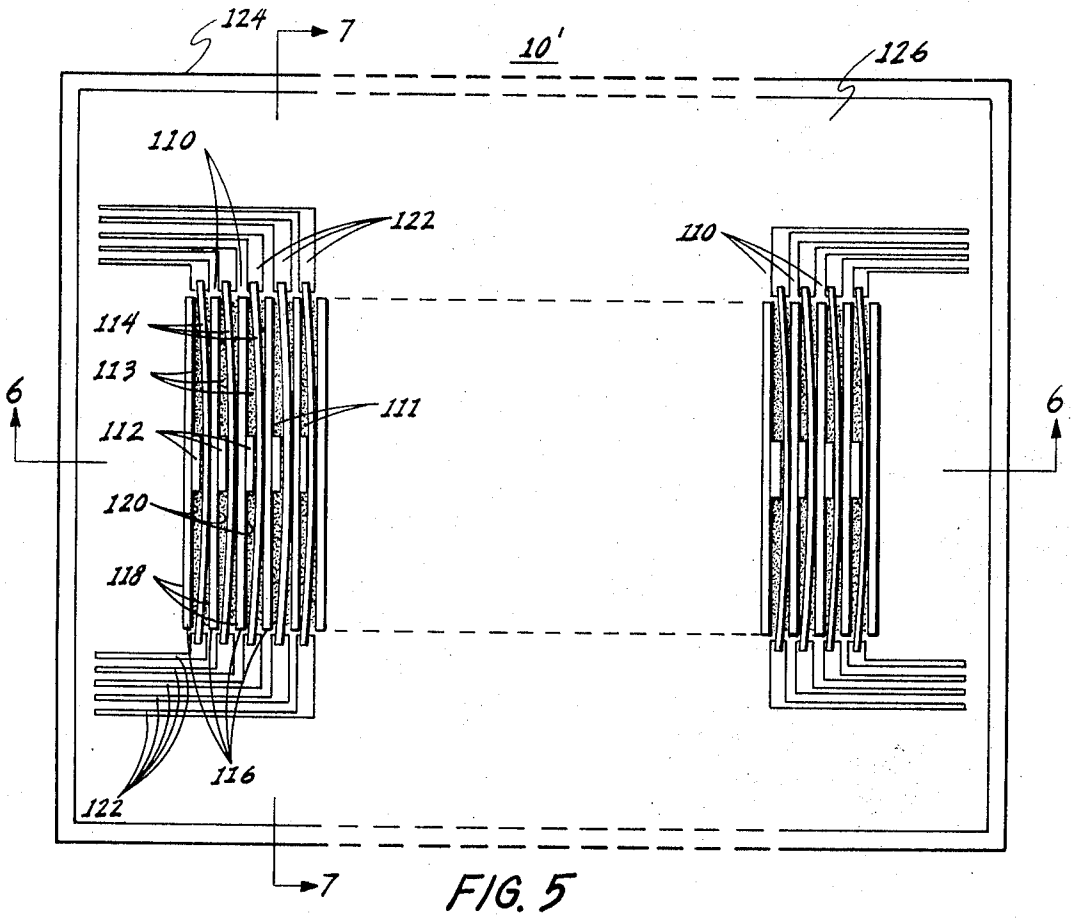


FIG. 5

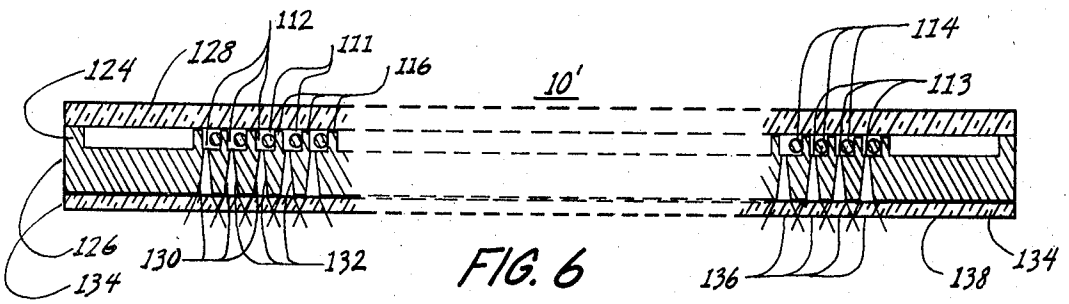


FIG. 6

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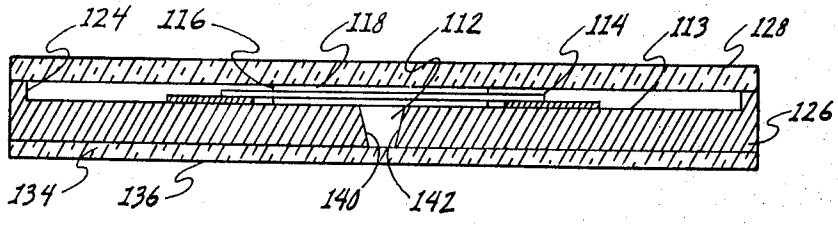


FIG. 7

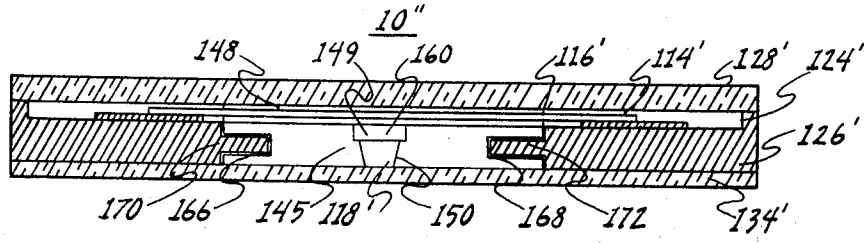


FIG. 12

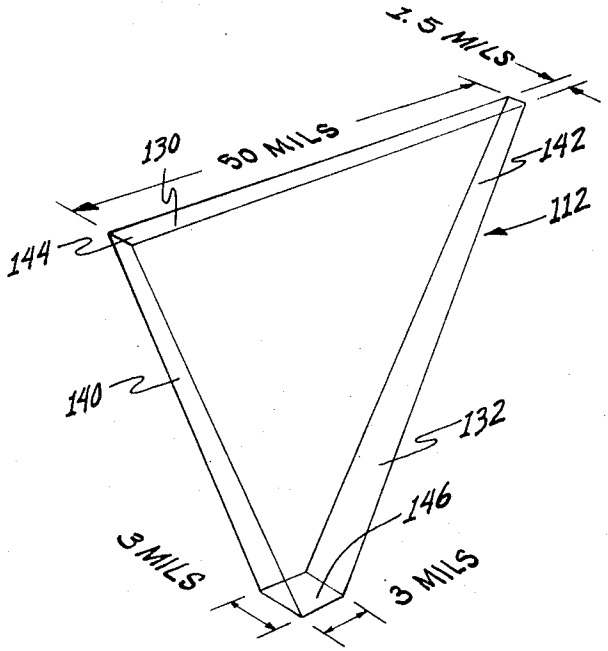


FIG. 8

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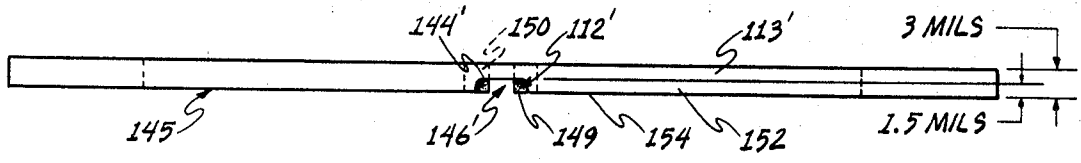


FIG. 9

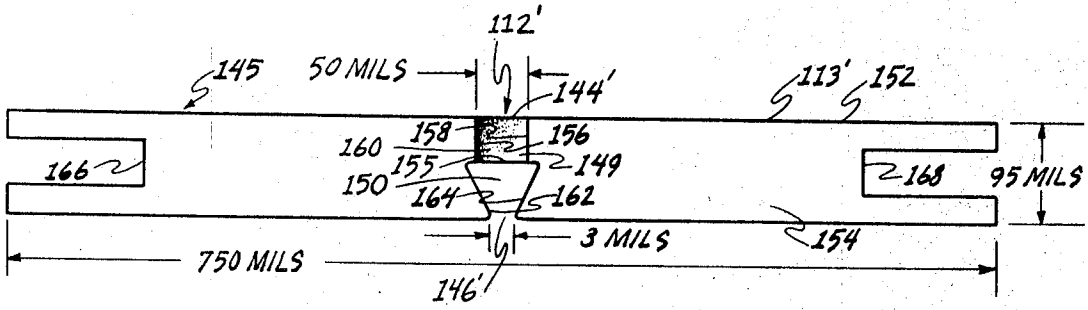


FIG. 10

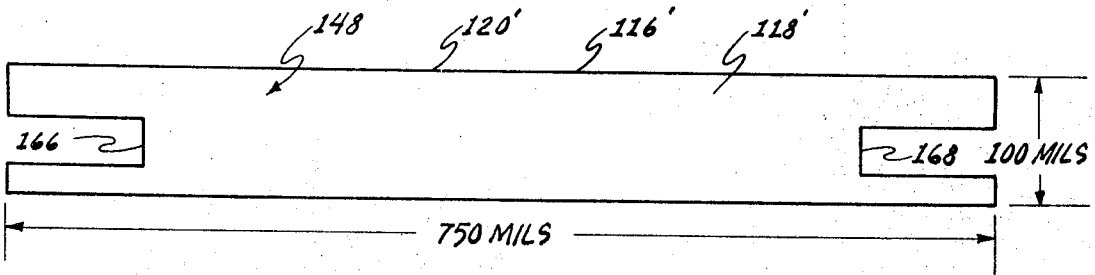


FIG. 11

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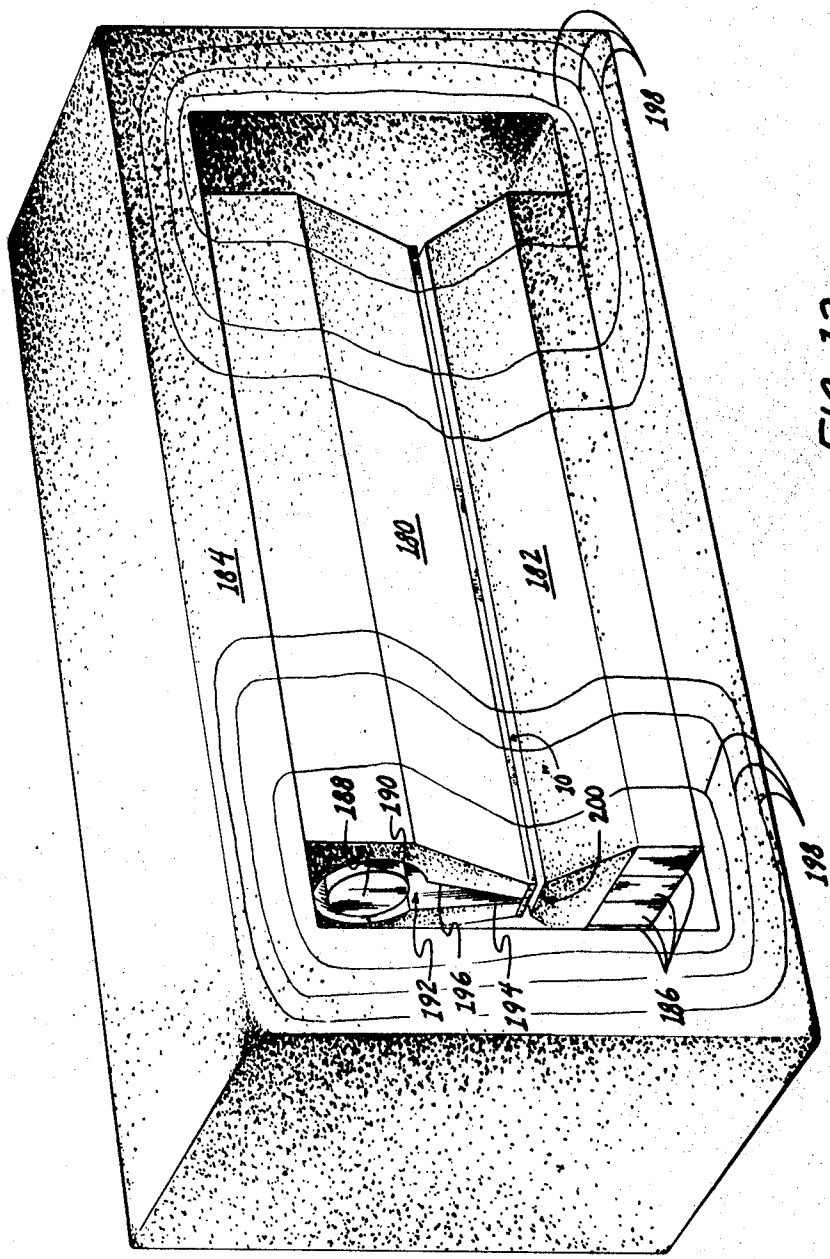


FIG. 13

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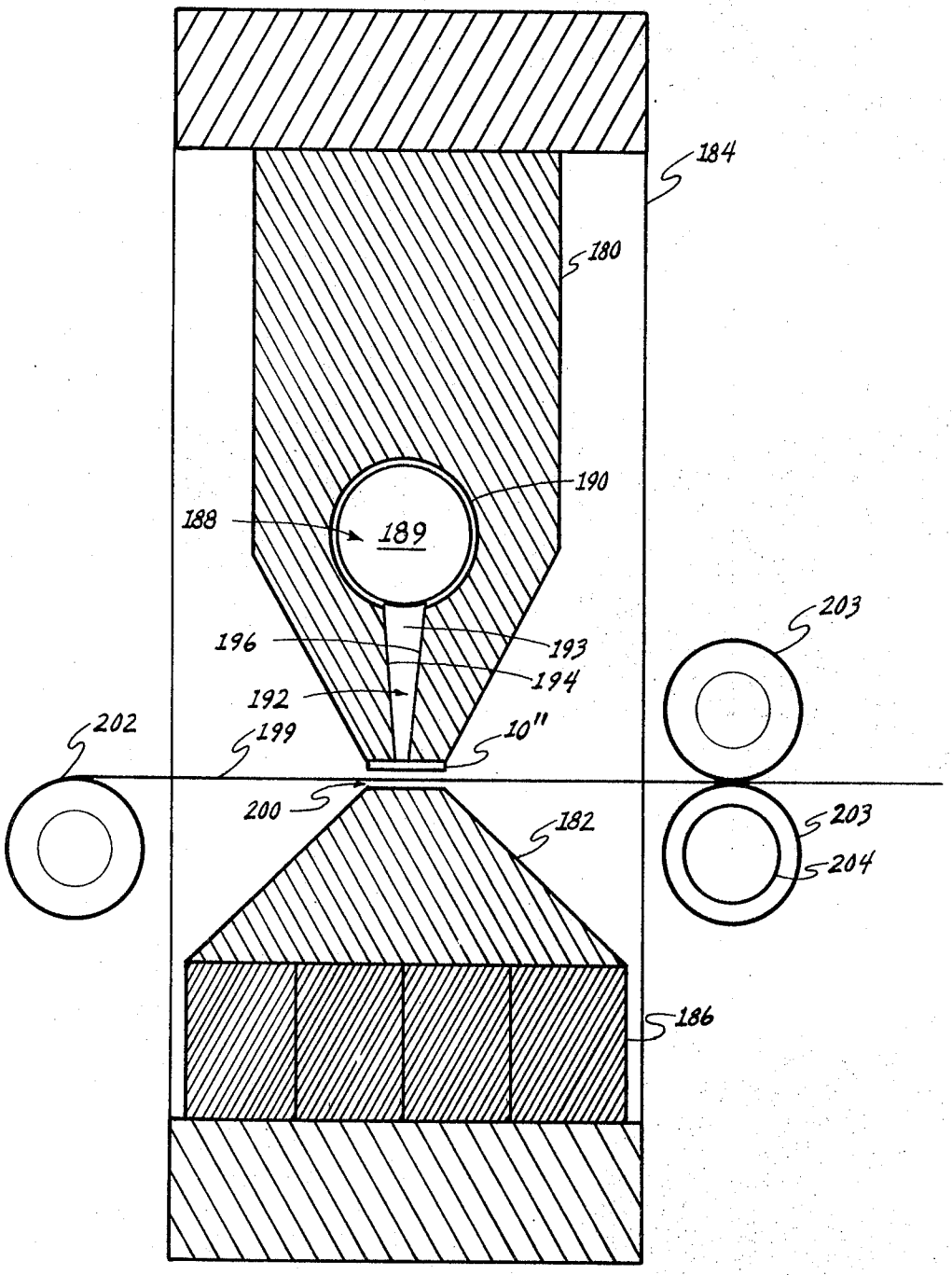

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FIG. 14

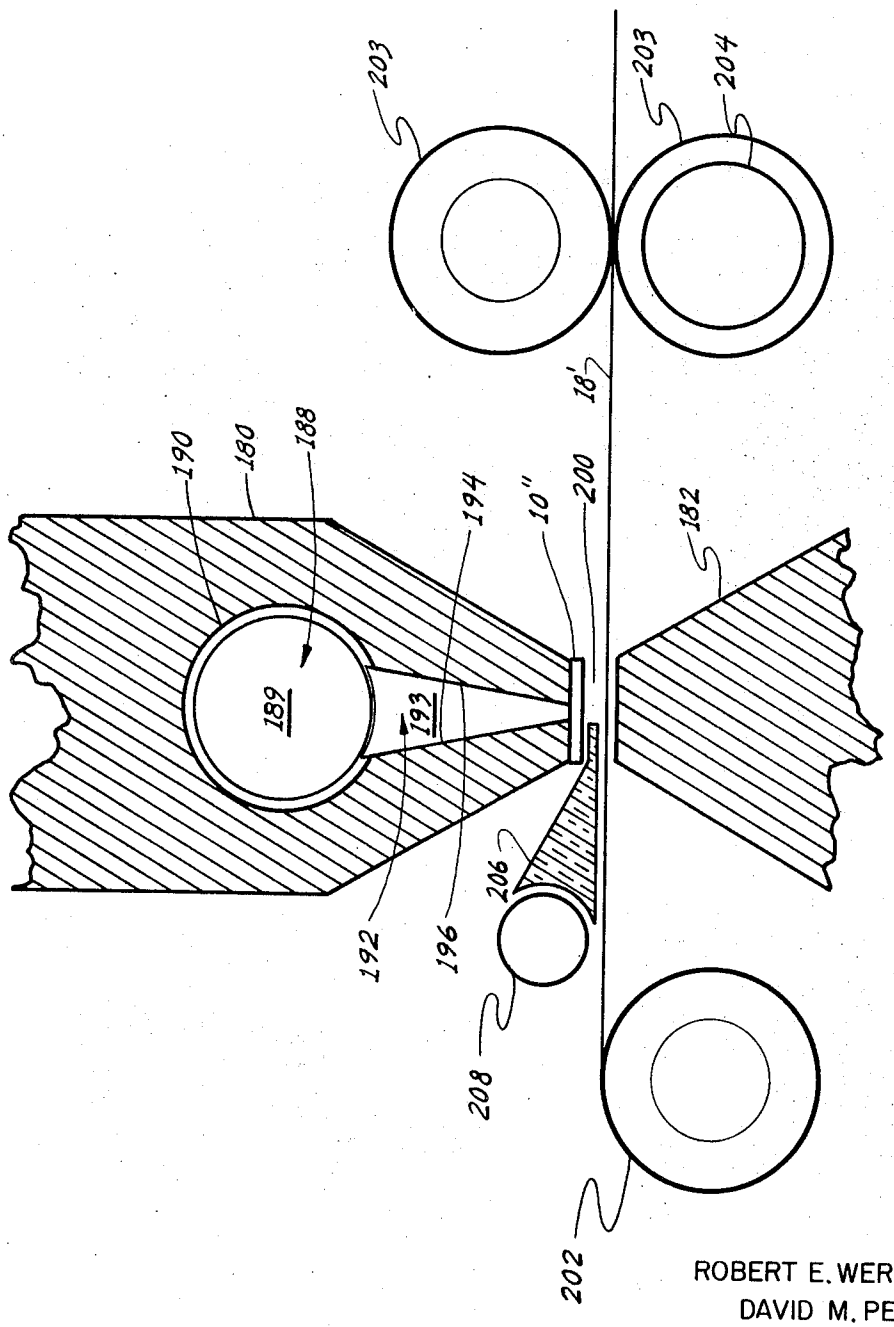


FIG. 15

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ELECTRO-MECHANICAL SHUTTER ARRAY

BACKGROUND OF INVENTION

This invention relates to an electromagnetically driven mechanical shutter, and to a system utilizing a plurality of such shutters.

Conventional reading and printing devices may use any one of a number of different techniques for selectively, systematically subjecting to radiation predetermined portions of a photosensitive material. In reading operations the material may be the sensitive surface of a vidicon or a matrix of photocells which receive radiation reflected or transmitted from the object to be read. In printing operations the material may be a light sensitive emulsion such as is used on photographic or treated copy paper. Often in the latter type of operations cathode ray tubes (CRT's) are used to expose the photosensitive material one spot at a time in series as the electron beam is moved across the face of the tube. CRT systems of adequate linearity are complex and expensive; also the intensity and the wavelength of the radiation from a CRT is necessarily limited to that which can be produced by its phosphor. Other high speed mechanical scanning systems using mirrors and the like have been used but these are generally large, cumbersome and difficult to keep aligned. Both the CRT and mechanical systems suffer from the limitations of serial operation which is inherently slower than parallel operation: serial operation is that in which a surface is irradiated or scanned one spot at a time, parallel operation is that in which all spots on a surface are simultaneously irradiated or groups of spots are simultaneously irradiated.

Parallel systems may include discrete element arrays such as charging pins, thermal elements, liquid crystals, light emitting diodes and other electro-optic elements. Charging pins require high voltage and so are not conducive to miniaturization or to use with integrated circuits; thermal elements are generally slow acting and provide poor contrast; liquid crystals are also slow and even the best liquid crystals suffer from low signal-to-noise ratio; and light emitting diodes are not as yet produced within sufficient tolerances so that the intensity of radiation produced can be depended upon to be the same for each diode, nor is the intensity sufficient to permit reasonable exposure speeds.

SUMMARY OF INVENTION

It is therefore an object of this invention to provide a simple, inexpensive, high signal-to-noise ratio, high speed, low voltage, low power, electromagnetically operated mechanical shutter capable of being used in a compact high density array for a high contrast, high resolution scanning system which may be used for reading or printing operations.

It is a further object of this invention to provide such a shutter capable of use with a radiation source whose intensity and wavelength are essentially independent of the shutter and shutter array.

It is a further object of this invention to provide such an array in which the line of spots exposed by the line of shutters is properly aligned and is fixed so that the alignment is inherently maintained from line to line.

It is a further object of this invention to provide such a shutter usable with an aperture made with simple, inexpensive, accurate laminations.

It is a further object of this invention to provide such a shutter which may be operated as a monostable device whose positions depend upon current flow above and below a threshold value or a bistable device whose positions depend upon direction of current flow above some threshold value, and to provide such a shutter which controls an aperture associated with it that transforms the shape of the radiation flux gated from a shape similar to the switching element to another desired shape.

It is a further object of this invention to provide such a shutter which when used in large numbers in an array may be actuated all seriatim, all simultaneously or simultaneously within groups actuated seriatim.

This invention features an electromagnetically driven mechanical shutter including a conductor element in a magnetic field for enabling the element to be moved laterally between first and second predetermined positions as a function of the current through the element, and means associated with the element for introducing current through it. Stop means adjacent at least one of the positions positively establishes that position of the element.

In a preferred embodiment the invention may include a low power, compact high resolution system of 200 spots per inch which may be used selectively to control the flow of information containing patterns of radiation to sensing means, which, for example, may be photoelectric cells in the case of reading machines or photosensitive paper in the case of printing machines. The system may employ a plurality of shutters in a linear array to accomplish full area read out of a document by scanning successive lines of the document as it passes the array. This arrangement permits either simultaneous or serial operation of the shutters. Separation of the radiation control device from the radiation source eliminates restrictions on the intensity and wavelength of the radiation used. Further, because of the simple design employed the shutters can be packed very closely in an array, control can be achieved over very small areas and resolution can be made very high.

DISCLOSURE OF PREFERRED EMBODIMENT

Other objects, features and advantages will occur from the following description of a preferred embodiment and the accompanying drawings, in which:

FIG. 1 is a block diagram of a system according to this invention which may be used as a printing device.

FIG. 2 is a block diagram of a system similar to FIG. 1 which may be used as a reading or sensing device.

FIG. 3 is a partial schematic diagram of a shutter according to this invention.

FIG. 4 is a diagram showing a variation of the shutter construction, and a control zone which may be controlled by a shutter according to this invention.

FIG. 5 is a partially detailed diagrammatic plan view of a linear array having a plurality of shutters for performing line scans according to this invention.

FIG. 6 is a cross-sectional view along lines 6—6 of FIG. 5.

FIG. 7 is a cross-sectional view along lines 7—7 of FIG. 5.

FIG. 8 is an axonometric diagrammatic line drawing showing the shape of an aperture associated with a shutter.

FIG. 9 is a plan view of an aperture lamination which may be used to form part of a shutter cell according to this invention.

FIG. 10 is an elevational view of the aperture lamination of FIG. 9.

FIG. 11 is an elevational view of a wall lamination which may be disposed one on each side of the aperture lamination to complete the shutter cell.

FIG. 12 is a view similar to that of FIG. 7 of a shutter cell of a linear shutter array formed with the laminations of FIG. 9, 10, and ll.

FIG. 13 is a diagrammatic axonometric view of a linear shutter array disposed in the space between two magnetic members, one of which contains a light source, mounted in a magnetic frame according to this invention.

FIG. 14 is an elevational cross-sectional view of a printing device according to this invention.

FIG. 15 is a cross-sectional view, similar to that of FIG. 14 with portions broken away, of a reading device according to this invention.

The invention may be embodied in a system in which a plurality of shutters in shutter array 10, FIG. 1, gate radiation from radiation source 12 to photosensitive material 14 in accordance with instruction signals from control 16. Radiation source 12 may provide radiation of any desirable wavelength and intensity to which photosensitive material 14 is responsive.

Shutter array **10** includes a plurality of individual shutters in some random or ordered array, either linear or two-dimensional. In one specific embodiment hereinafter disclosed those shutters are disposed in a linear array of approximately 200 shutters per inch and means are provided for moving a photosensitive material such as a sheet of light sensitive paper past the array so that the paper may be exposed in accordance with the instruction signals as it passes beneath the array. Photosensitive material **14** may be any type of material sensitive to radiation to record images such as photographic film or any of various kinds of paper used in copier machines. Each shutter may control a spot of radiation at the paper of approximately 5 mils in the direction of paper motion and approximately 5 mils orthogonal to that direction. Thus if an 8½ × 11 inch sheet of paper is processed along its longest dimension it will be exposed to 2,200 lines, each having 1,700 spots or positions, in a raster similar to that produced by a CRT, which raster contains 3,740,000 spots or positions. Each spot in each line is exposed or not exposed in accordance with the instructions delivered to control **16** to form a pattern of information such as alphanumeric characters, graphs, drawings or the like. Thus the shutter both determines whether or not light passes to the photosensitive material and determines the precise area on the medium that receives the light. In this sense, it serves both a modulation and a deflection function. The exposure of each spot produced need not have only a binary quality wherein a shutter is either open or closed during the entire exposure time and the corresponding spot on the paper is either fully exposed or not exposed. Rather, the time during which a shutter is open may be varied to vary the exposure, or a radiation element whose intensity may be varied may be associated with the shutter array, to give the exposure a gray scale or analog quality.

The system of FIG. **1** may be converted to operate as a reading system, FIG. **2**, by substituting an item **18** to be sensed in the position of the photosensitive material **14** and disposing the photosensitive material **14'** in a position to receive radiation reflected from (or transmitted through) the item **18**. The item **18** may contain holographic, typewritten or printed alphanumeric characters, graphs, or any other form of information. Photosensitive material **14'** may be a photosensitive substance, photoelectric cells, or any other device which may be used to convert incident radiation to electrical signals to produce an output when an item is sensed. Control **16** receives instructions which indicate the manner in which the shutters are to be actuated and produces signals to actuate the shutters accordingly. The individual shutters in the array may be actuated simultaneously, sequentially, simultaneously within sets of shutters which sets are actuated sequentially, or in any other systematic or even random manner. Rather than controlling passage of radiation to the item to be sensed, the item may be flooded with radiation and the array placed to shutter reflected radiation incident upon the photosensitive material if desired.

A shutter according to this invention, FIG. **3**, may be constructed by fixing a conductor element or wire **70** to two pins, **72**, **74** on either side of aperture **76** in base **78**. At least the central portion of wire **70** proximate aperture **76** is opaque so that when the force F_R arrow **79**, the force tending to retard motion of wire **70**, is overcome and wire **70** is compelled to move to the right by a force F_D arrow **80**, it covers aperture **76** and blocks passage of radiation therethrough. The force F_D is developed by the interaction of magnetic field B, arrow **82**, and the current I, arrow **84**, produced in wire **70** by battery **86** through resistor **87** and reversing switch **88** when on-off switch **90** is closed. A mechanical stop, pin **94**, is provided to positively position wire **70** when it is clear of aperture **76**, when switch **90** has been opened. Wire **70** thus may be arranged to have two stable positions one clear of aperture **76** and one blocking aperture **76**. The wire **70** may be made to block aperture **76** when a current flows in it sufficient to generate force F_D and clear aperture **76** when no current flows or current flows which is insufficient to produce force F_D. Or, conversely, wire **70** may be made to clear an aperture when a current flows in it sufficient to generate force F'_D and to block an aperture when no current flows or current flows which is insufficient to produce force F'_D. Alternatively, wire **70** may be arranged so that at its rest position or no current position it neither totally blocks nor totally clears aperture **76**. Then a current I, arrow **84**, sufficient to generate force F_D, arrow **80**, is required to overcome force F_R and move wire **70** to block aperture **76** and a current I', arrow **96**, sufficient to generate force F'_D, arrow **98**, is required to overcome force F'_R, arrow **100**, and move wire **70** to clear aperture **76**.

The use of a mechanical stop provides many advantages over similar prior art shutters especially in high density arrays. The direction of the current through the wire, once a threshold value is exceeded, positively determines the open or closed state of the shutter: the shutter may be moved between its opened and closed positions either by the conditions in which there is sufficient current to produce F_D or there is not sufficient current to produce F_D or by the conditions in which there is sufficient current in a first direction to produce force F_D or there is sufficient current in the opposite direction to produce force F'_D. When the stop is used to establish the position of the wire in which the aperture is blocked or closed, the optical modulation, which is the ratio of the difference in radiation transmitted between the open and closed shutter positions to the radiation transmitted in the open shutter position, may be very high since the stop accurately locates the wire over the aperture. The addition of a second stop further provides a uniform open position so that a uniform switching time is obtainable. Further, even with only one stop, the one defining the closed position, when the reversing current conditions of the bistable mode of operation, rather than the sufficient current—insufficient current conditions of the monostable mode of operation, are used to switch the wire, the precision required in initially assembling the wire is not critical. Additionally, this technique permits using a relatively loosely suspended element or wire so that the switching time may be decreased compared with prior art shutters using the same driving force F_D. Thus variations in wire tension such as caused by variations in temperature or construction do not significantly effect alignment or switching time.

Although the operation of a shutter according to this invention has been shown in FIG. **3** in relation to an aperture **76** which may be completely blocked by the conductor element **70**, these are not limitations of the invention. For example a conductor element **20**, FIG. **4**, may be used having a coating or shell **22** or a core **24**, or both a shell and a core of another substance, such as teflon, to increase the size of the area that may be blocked without appreciably increasing the force required to move the element **20**. The element **20** may move between stops to gate radiation in an area which is larger than the element in length, width or both dimensions, as shown in FIG. **4** where radiation from source **26** is focused by lens **28** at point **30** the focus of lens **32**. As shown element **20** with shell **22** and core **24** functions to gate radiation in only a portion of aperture zone **34**: with element **20** disposed as shown only area **36** is blocked; with element **20** located as shown in dashed lines only area **38** is blocked. Of course, the element **20** may be disposed to move across the focal point **30** and either completely block or pass radiation from lens **28** to lens **32**.

In a preferred embodiment the shutter of this invention is used in large numbers in some form of array **10**, FIG. **1**. Such an embodiment is shown in FIGS. **5** and **6** with a linear array **10'**. Each shutter **110** includes a wire **114** in a cell **111** including an aperture **112** in base **113** between a pair of walls **116** preferably shared with adjacent shutters. Walls **116** constitute two stops, such as do pins **92**, **94**, FIG. **3**: surface **118** acts as a stop for wire **114** when it is positioned in the open shutter condition pictured in FIG. **5** by a current in a first direction and surface **120** acts as a stop for wire **114** when it positioned over aperture **112** in the closed shutter condition by a current in the opposite direction. Aperture **112** is located immediately

adjacent surface 120 so that when wire 114 is against surface 120 it completely covers aperture 112. Wires 114 may be attached at each end to electrical conductors 122 such as those plated or etched on printed circuit boards. They may be attached either directly by welding, soldering, or adhering with a conductive material such as some epoxy compounds, or through intermediate connectors such as pins 72, 74 of FIG. 3. The attachment serves both as an electrical connection to conduct current from control 16 through the wire 122 and as a mechanical connection to anchor wire 114, or separate means may be provided for the electrical and mechanical connections. Preferably wires 114 are aluminum annealed such that its spring constant is low, which because of its light weight and low spring constant requires little power to move and which may be anodized to provide electrical insulation between the wire and walls or other parts of the array. The size of aperture 112, the height of walls 116 above base 113, and the spacing between walls 116 is in part dependent upon the diameter of wire 114. As a specific example of sizes involved with a wire 114 of 1.5 mils diameter and about three-fourths inch long, walls 116 may be spaced apart 3 mils, extend 5 mils above base 113, and aperture 112 may be 50 mils in length and slightly less than 1.5 mils in width. For high speed applications a small conductor element is used in order to minimize mass and to permit increased heat dissipation and higher current per unit area. If larger apertures or control zones are to be gated, a coating or core of another substance may be included as part of wire 114 to increase its size without increasing the drive current required as explained supra with reference to FIG. 3.

A rim 124, FIG. 6, on main member 126 supports a transparent plate 128 which rests on the tops of walls 116 to enclose the upper portion of the array. Wires 114 are positioned just above the surface of bases 113 and below plate 128 so that there is as little as possible frictional force retarding the movement of wires 114. Apertures 112 expand toward their lower ends because of the divergence of surfaces 130, 132 which have highly specular finishes to improve the transmission efficiency of the apertures. In this form the aperture 112 functions as a light tunnel to transform the shutter shape to the desired image shape.

As a result of the divergence of surface 130, 132 the width of the aperture 112 at the lower edge of member 126 may be 3 mils. Since the radiation emerging from the aperture 112 is diverging the radiation from adjacent shutters 110 will overlap at some distance from the shutters. A second transparent plate 134 having a predetermined thickness and refractive index may be mounted on the lower surface of member 126 so that each of the spots 136 of radiation from each aperture just meets the spot from the neighboring aperture at the outer surface 138 of plate 134. Plate 134 serves to complete the enclosure of the array so that it may be totally protected from dust, and other foreign matter and also serves to positively position photosensitive printing material relative to the shutter array.

Aperture 112, as well as being expanded in its width dimension from 1.5 mils to 3 mils is reduced in its length dimension from 50 mils to 3 mils by the convergence of its other two specular surfaces 140, 142, FIG. 7. A typical aperture has a shape as shown in FIG. 8 where the upper opening or inlet 144 is 1.5 mils in width and 50 mils in length and the outlet 146 is 3 mils in width and 3 mils in length being expanded to a 5 by 5 mils spot size at the outer surface of plate 134. The shape of the aperture is a significant feature of the design as it contributes to the increased optical efficiency of the array, where optical efficiency is expressed as the ratio of the power density transmitted with shutter open to the power density incident on the aperture or array. Thus by increasing the size of the inlet of the aperture along the length of the wire the amount of incident radiation received by the aperture is increased while by decreasing the size of the outlet the radiation density is increased thereby increasing the optical efficiency. The aperture shaping has particular value for it not only increases optical efficiency but also allows closer spot to spot spacing as discussed in reference to FIG. 6, supra.

The improved performance of the shutter of this invention may be better understood by a development of certain fundamental relationships involved in the operation of the system. The force balance equation for the shutter may be expressed as: $F_D = F_R$ or $F_D = F_A + F_B + F_F$ where the force F_R retarding movement of the shutter includes forces F_A, F_B and F_F.

F_A, the inertial force, is the mass, m, of the moving element times its acceleration, d^2x/dt^2, and ultimately determines the maximum switching speed of the shutter. Use of smaller diameter wire and lighter metals, such as aluminum, serve to minimize this force and provide faster switching.

F_B, the restoring force, tends to return the element to its rest position, which in our design may be anywhere between the stops. It may be simply described as a spring constant K times the displacement x. The magnitude of this may vary considerably depending upon how the element is suspended and the material from which it is made. If the element is initially suspended in high tension, T_o, such that the increase in tension, ΔT, due to the lateral displacement is small, $\Delta T << T_o$, the restoring force is found by calculating the vectorial redirection of the tension T_o, i.e., $F_B = T_o x/L$ where L is the length of the element. This is the case of many shutters of the prior art. The opposite extreme is the case in which the element is suspended with nearly zero tension; here $\Delta T >> T_o$ and the force required to cause displacement x is given by $F_B = CEIx/L^3$ where E = modulus of elasticity of the material used and the cross-sectional moment of inertia, $I = d^4/32$ for an element of circular cross section of diameter, d, and C is a constant. Thus the bending force can be written in terms of d: $F_B = C'Ed^4x/L^3$. It is desirable to suspend the moving element as loosely as possible; however some small tension is required in order to place the element in position. A practical case exists where $\Delta T \approx T_o$ and the net force is a combination of the two cases described above. The preferred construction of the shutter of this invention fits this case and a material is chosen to minimize this force within permissible design limits. The result is that the shutter maintains a force $F_B << F_A$ for the desired switching times; thus F_B may be neglected in the dynamic analysis to follow.

F_F, the frictional force, may be expressed as some surface co-efficient of friction, μ, times the normal force, N, pushing the element against the surface. Base 113 and plate 128, FIGS. 5, 6, 7, present surfaces upon which the moving element may drag. Walls 116 are made sufficiently high such that contact with these surfaces will be minimized and N will be small, i.e. $F_F << F_A$.

F_D, the driving force, is the Lorentz force, $F_D = iLB_Y$ where i is the current in the element and B_Y is the magnetic field intensity, assumed for simplicity to be spatially uniform, in the direction normal to the array. In practice the current is limited by thermal dissipation and the magnetic field may be on the order of 1.0–2.0 webers/m^2 or more.

The force balance equation is then: $F_A \cong F_D$ or $m\, d^2x/dt^2 = iLB_Y$ where F_B, $F_F << F_A$, F_D. Taking x, $dx/dt = 0$ at $t = 0$, the above equation has the solution: $x = iLB_Y t^2/2m$ which is valid during the excursion of the wire from one stop until the time it first hits the other stop. If this total excursion is called δ, the switching time may be written: $t_s = [2m\delta/iLB_Y]^{1/2}$. For shutters of this invention typical switching time is 50 microseconds: the shutter requires 50 microseconds to open and 50 microseconds to close. If the shutter remains in the position to which it was switched in any particular actuation for 50 microseconds then the total shutter cycle time is 150 microseconds. Thus for a resolution of 200 lines per inch in the direction of paper motion the printing or reading rate is 3×10^{-2} seconds per inch of paper or approximately 33 inches of document per second may be fed past the shutter array.

The array of shutters of FIGS. 5, 6, 7 may be constructed using two different types of laminations: an aperture lamination 145, FIGS. 9, 10 and a wall lamination 148, FIG. 11. In FIGS. 9, 10 and 11 similar parts have been given primed numbers with reference to FIGS. 5, 6 and 7. In a typical construction aperture lamination 145 may be 95 mils wide, 3 mils thick and 750 mils in length and has an aperture 112′ including a

recess **149** and a hole **150**. Recess **149** extends from one longitudinal edge **152** along base **113'** to approximately half way across the width of lamination **145**. Recess **149** extends 50 mils in the longitudinal direction of lamination **145** and approximately 1.5 mils into its thickness dimension from surface **154**. At its inner end **155** recess **149** communicates with hole **150** which is through the thickness of lamination **145** and at its other end hole **150** forms outlet **146'** which is 3 mils in length and 3 mils across. The aperture **112'** is formed by recess **149** and hole **150** in conjunction with two neighboring wall laminations **148** which may be 750 mils long, 100 mils wide and 2 mils thick, FIG. **11**. Surface **120'**, not visible in FIG. **11**, closes recess **149** and the surfaces **118'**, **120'** of two different laminations **148** close hole **150** when an aperture lamination **145** is between two wall laminations **148**. The aperture **112'** so formed does not have exactly the shape of the aperture **112**, FIG. **8**,: rather its upper portion formed partially from recess **149** is essentially rectangular with two pairs of parallel facing sides **156**, **158** and **160** and a portion of surface **120'** of an adjacent wall lamination **148**; and its lower portion formed partially from hole **150** has one pair of facing parallel walls formed from surfaces **118'**, **120'** of two adjacent wall laminations **148** and two converging sides **162**, **164**. However, although the shape of aperture **112'** is not identical with that of aperture **112** the inlet and outlet apertures are identical and so substantially the same effect on efficiency and spot overlap or continuum is achieved but at greatly reduced manufacturing costs. The laminations **145**, **148** may be formed by chemical etching of metals such as beryllium-copper, or nickel, or by plastic molding, or by thin metal or plastic stamping. The array may also be made without using laminations by chemically etching thin or thick films or bi-metallic strips, glass or ceramic etching, plastic molding, electroforming or a combination of these processes. Since laminations **148** are 10 mils in width and laminations **145** only 95 mils, walls **116'** extend 5 mils above base **113'** as walls **116** did above base **113**, FIGS. **5**, **6**, **7**. Registration notches **166**, **168** in each end of laminations **145**, **148** enable them to be assembled in a linear shutter array **10''** on an assembly member **126'**, FIG. **12**, having corresponding mating portions **170**, **172** and being constructed generally as the array **10'** of FIGS. **5**, **6**, **7**.

The use of laminations to construct the shutter cells provides certain advantages over other techniques. Aperture position is certain to be justified to surface **120'** providing a high signal-to-noise, on-off, ratio and contributing to overall uniformity. The dimensions of each shutter can be made very accurate and uniform and the array can be extended indefinitely.

The shutter array **10''** may be subjected to a magnetic field B, FIG. **3**, by being disposed between two elongated magnetic members **180**, **182**, FIG. **13**, contained in a magnetic frame **184** which functions as a return path for the field developed by magnets **186** in lower member **182**. Upper member **180** supports an elongate light source **188** in cylindrical channel **190** which transmits the light through light transfer slot **192** formed of converging specular walls **194**, **196** to array **10''**, at its lower end. Source **188** is an independently controlled segmented light source such as a series of gas discharge tubes or electroluminescent panels which can on command illuminate the entire length of the array or separate segments in sequence. The path of the magnetic field B partially indicated by lines **198**, is from magnets **186** through member **182**, air gap **200**, array **10''**, member **180** and around frame **184** back to magnets **186**. Members **180**, **182**, **184** may be soft iron and magnets **186** may be permanent magnets, or an electromagnet assembly may be employed. The magnetic structure of FIG. **13** combines an efficient and uniform magnetic field with a topology permitting easy movement past the array of photosensitive material or other substances to be printed or read by means of the array.

Printing may be accomplished with the structure of FIG. **13** by operating it with photosensitive paper **199**, FIG. **14**, which is drawn beneath array **10''** through air gap **200** from a roll **202** by means of rollers **203** driven by stepping motor **204**. The stepping motor moves the paper **199** past array **10''**, in synchronism with the switching of wires **114** in shutters **110**, in increments of 5 mils equal to the length of the illuminated spot in the direction of paper motion. In this manner alphanumeric characters. graphs, designs and any other information may be printed incrementally as the paper advances.

The structure of FIG. **14** may also be used as a reading machine, FIG. **15**, in which the item **18'** to be sensed or read is substituted for the photosensitive paper **199** in air gap **200** beneath array **10''**. As item **18'** is moved through gap **200** and array **10''** is switched to illuminate successive lines of item **18'** the reflected light therefrom is collected and transported by a segmented light pipe **206** from the illuminated area of item **18'** to a photoelectric sensor **208** which may include a plurality of photocells in a linear array aligned with the shutters in array **10''** and may be sensed in synchronism with actuation of their corresponding shutters. In both FIGS. **14** and **15** light source **188** is segmented, segment **189**, and slot **192** is sectional, section **193**, so that radiation to each group of shutters in array **10''** is supplied by a separate segment of source **188** through a separate section of slot **192**. Thus corresponding shutters in each group may be actuated simultaneously, the associated light source segment either being on or off according to the requirement of the shutter. Exposures through the shutters of array **10''** may be operated as a gray scale system rather than merely a black and white system: each segment of source **188** may be independently energized to provide any particular intensity radiation to be gated by its corresponding shutter. Gray scale operation may also be achieved by varying the time that a shutter remains open.

Although only one form of shuttering technique and shutter, one form of array, and one machine for using a linear array has been illustrated, many other embodiments of such a technique are possible and are within the concept of this invention.

Other embodiments will occur to those skilled in the art and are within the following claims:

What is claimed is:

1. An electromechanical shutter system for controlling illumination of a row of contiguous minute equal areas in linear array comprising:

a series of slope-walled apertures one corresponding to each of the areas to be illuminated, and arranged side by side, each aperture having its output end of the size and shape to cast a light beam covering the area to be illuminated thereby, and its input end substantially narrower than the output end in a direction along the row and substantially longer than the output end in a direction transversely of the row to embrace adequate input illumination;

a plurality of conductor elements, one for each aperture, and each of a width adequate to block the input end of an aperture, each conductor disposed transversely of said row and parallel to the length dimension of the input end of one of said apertures;

means associated with each of said elements for introducing a controllable electric current therethrough; and

means providing a magnetic field coacting with the fields of said elements, when energized, to shift the same laterally either into aperture exposing or aperture blocking position.

2. A shutter system as set forth in claim **1** in which the last named means comprising a magnet element extending lengthwise of the row of areas in close proximity to said conductor elements, said magnet element being apertured to admit radiation through the magnet from an illumination source to impinge upon the conductor element.

3. An electromechanical shutter system including an array of electromagnetically driven mechanical shutters comprising:

a plurality of conductor elements for disposition in a magnetic field for enabling the elements to be moved laterally between first and second predetermined positions as a function of the current through the elements;

means, associated with each of said elements, for introducing current therethrough;

stop means associated with each of said elements and adjacent one of said positions for positively establishing one of said positions of a said element; and

magnet means for producing the magnetic field, said magnet means including:

a first elongate member having an elongate recess therein for receiving a radiation source, and radiation transferring means extending from said recess to the exterior of said member,

a second elongate member,

a main frame for internally mounting said members in spaced, parallel, juxtaposition with said radiation transferring means facing said second member and for providing a magnetic return path for the field established in the space between said members for irradiating under control of said shutters objects fed through said magnetic frame in the space between said members.

4. The system of claim 3 in which said main frame is a closed rectangular core.

5. The system of claim 3 in which one of said members includes a permanent magnet for producing a magnetic field from that member through the space, and the other member and returning through the main frame.

6. The system of claim 3 in which said radiation source and said radiation transferring means each includes a plurality of discrete members, one of each such members being associated with a group of said shutters for independently providing radiation to each group of said shutters for permitting gray scale operation through said shutters.

7. The system of claim 3 in which radiation transferring means is a slot having highly reflective walls which converge toward the exterior of said member.

8. An electromechanical shutter system including an array of electromagnetically driven mechanical shutters comprising:

a plurality of conductor elements connected to electrical terminals and disposed in a linear array transverse to their longitudinal axes in an orthogonal magnetic field;

means for introducing current to said elements to move them between first and second positions in the magnetic field;

stop means associated with each of said elements and adjacent one of the positions for positively establishing the first position of one of the elements and the second position of an adjacent element; and

magnet means for providing a magnetic field comprising:

a first elongate member having an elongate recess therein for receiving a radiation source, and radiation transferring means extending from said recess to the exterior of said member,

a second elongate member,

a main frame for internally mounting said members in spaced, parallel, juxtaposition with said radiation transferring means facing said second member and for providing a magnetic return path for the field established in the space between said members for irradiating under control of said shutters objects fed through said magnetic frame in the space between said members.

9. The system of claim 8 further including an aperture associated with each of said shutters, each said aperture formed in a cell which is formed by two wall laminations between which is included an aperture lamination including a hole extending laterally through the thickness dimension, part way across the width dimension and opening onto a longitudinal edge of the shutter lamination, and a recess into the thickness dimension of, and extending from the hole to the other longitudinal edge of, the aperture lamination.

10. The system of claim 9 further including a transparent plate adjacent the shutter array for positively positioning proximate the shutter array items to be subjected to radiation gated by the shutter array.

11. The system of claim 10 further including a photosensitive sensor associated with each of said elements for sensing radiation from an object.

12. The system of claim 9 in which each of said apertures has an inlet of 50 mils by 1.5 mils and an outlet of 3 mils by 3 mils.

13. The system of claim 12 in which each of said elements is approximately 750 mils in length.

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